

**ISARLAB - Inverse Synthetic
Aperture Radar Simulation and
Processing Tool**

Brett Haywood, Ross Kyprianou,
Carmine Fantarella and
James McCarthy

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ISARLAB - Inverse Synthetic Aperture Radar Simulation and Processing Tool

*Brett Haywood, Ross Kyprianou, Carmine Fantarella
and James McCarthy*

**Surveillance Systems Division
Electronics and Surveillance Research Laboratory**

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ABSTRACT

ISARLAB ("Inverse Synthetic Aperture Radar Laboratory") is a computer program designed as a research and training tool for those interested in the field of radar imaging. The system runs under MATLAB and is capable of simulating the radar returns from complex targets such as ships and aircraft, and processing these to form high range resolution (HRR) profiles and inverse synthetic aperture radar (ISAR) images. In addition to simulating various radars and targets in realistic scenarios, ISARLAB can accept and process experimentally collected radar data. This document represents the combination of a Reference Guide and a User's Guide to the software package, as well as providing a brief introduction to radar imaging.

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Executive Summary

Inverse Synthetic Aperture Radar (ISAR) imaging is a relatively mature technique for generating 2-dimensional high resolution maps or images of target scattering. These images have the potential to allow the target of interest to be distinguished from other types of similar targets (i.e. the classification problem). ISAR images of all categories of vehicles (aircraft, ships and land vehicles) have been produced, but the technique has found significant military application in airborne maritime surveillance. This is predominantly because the rotational motions of roll, pitch and yaw induced on a ship by the sea can be substantial and thus provide a ready mechanism by which Doppler distributions across the target's structure can be consistently measured. The resulting 2-D image is a projection of the target's scattering centres onto a range versus Doppler grid, where the projection plane is defined as being parallel to the radar line-of-sight range vector and perpendicular to the effective axis of rotation of the target. To illustrate this effect, a ship undergoing only roll motion will produce an end-on projection, a pitching ship will generate an elevation view and a yawing ship will yield a plan image.

In reality ships undergo a combination of roll, pitch and yaw motions that yield a complex and continually changing effective axis of rotation. The resulting ISAR images can therefore be a multitude of visually unusual oblique projections. This leads to the challenge of training radar operators to understand the images acquired by the radar and subsequently, to be able to interpret them sufficiently to perform the classification task.

The Australian Department of Defence is currently in the process of acquiring a new radar system as part of a comprehensive upgrade to the Royal Australian Air Force (RAAF) squadron of P-3C Orion maritime surveillance aircraft. The radar, being supplied by Elta of Israel, contains among other features, range profiling and ISAR imaging modes. This will be the first radar in the Australian Defence Force (ADF) inventory to incorporate a high resolution imaging capability, which means that training of radar operators in the effective use of this new technology is a significant issue. Ideally, training would be conducted using an extensive database of imagery collected from the operational radar. However, before the system enters routine service and begins to collect imagery, this database will not be available. One solution to the problem of insufficient ISAR image data for training is to generate synthetic data.

The Surveillance Systems Division (SSD) of the Defence Science and Technology Organisation (DSTO) has developed a software tool for simulating radar returns and processing them to form range profiles and ISAR images. This tool, called ISARLAB, allows the user to define the scenario to be simulated using models for the radar waveform, the radar and target geometry, the target motions and, most importantly, the target scattering. Generation of quality target scattering models is key to the degree of realism which can be achieved with the system. The approach taken is to generate a point scatterer model for the target of interest from the results of an in-house developed electromagnetic prediction code called GSC (General Scattering Code).

The problem with the whole task of ISAR image simulation now becomes one of producing sufficiently detailed CAD models of the targets of interest for input to GSC. Although this problem is not technologically challenging, the job of constructing high fidelity CAD models requires considerable effort and/or expense. One remaining question, however, is the degree of model accuracy needed to produce ISAR images with sufficient realism for the purpose of radar operator training. This requirement will also impact on the number of point scatterers needed in the model, and therefore on the computation time required by ISARLAB. This number is not known at this stage, but it appears that models with a few hundred point scatterers will be acceptable. Work is continuing in this area and validation will be achieved by a comparative analysis using real ISAR imagery.

In summary, this document represents the combination of a Reference Guide and a User's Guide to the ISARLAB software package, as well as providing a brief introduction to radar imaging theory. It is believed that ISARLAB will prove beneficial to radar operator training by helping to develop an understanding of radar imaging mechanisms and the strengths and weaknesses of high resolution radar technology in an operational role.

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Contents

Contents	i
Tables	iv
Figures	iv
1. Introduction.....	1
2. Inverse Synthetic Aperture Radar (ISAR)	2
2.1 Basic ISAR Theory	2
2.2 Radial Motion Compensation.....	4
3. The ISARLAB Model.....	5
3.1 Modelling Radar and Target Motion.....	6
3.1.1 Gross Motion	7
3.1.2 Induced Motion	9
3.1.3 Target Alignment	11
3.2 Modelling Radar backscatter	11
3.2.1 The Target Scatterer Model	12
3.3 Modelling the Radar Signal Waveform.....	13
4. Getting Data and Information	14
4.1 Simulating Radar Returns	15
4.2 Reading a Raw File of Radar Returns.....	16
4.3 Saving and Loading Information	16
5. Radar Signal Processing.....	17
6. Display Processing	19
7. System Description.....	20
8. Introduction to Using ISARLAB	22
8.1 Installing ISARLAB	22
8.2 Using ISARLAB.....	23
8.2.1 Starting ISARLAB.....	23
8.2.2 The Graphical User Interface.....	23
8.2.3 User Input	23
8.2.4 Stored Information and Filenames	24
8.2.5 Prompts and Messages	24

8.2.6	Exiting ISARLAB.....	25
9.	Navigating ISARLAB.....	25
9.1	The Display Panel	25
9.1.1	Purpose	25
9.1.2	File menu.....	25
9.1.3	Window Menu.....	27
9.1.4	Display Menu	28
9.1.5	Features Menu	30
9.1.6	Overlay Menu.....	30
9.1.7	Help Menu	30
9.2	The Button Bar.....	30
9.2.1	Purpose	30
9.2.2	Using this window	31
10.	Using Trial Data.....	32
10.1	Data Input Using the Load Menu.....	32
10.1.1	Purpose.....	32
10.1.2	Using this window	33
10.2	Data Input Using the Import Menu	34
10.2.1	Purpose.....	34
10.2.2	Using this window	34
11.	Simulation.....	36
11.1	Data Input Using the Load Menu.....	36
11.2	Specifying Dynamics: Scenario Setup	36
11.2.1	Purpose.....	36
11.2.2	Using this window	37
12.	Signal Processing	41
12.1	Choosing the Radar: Signal Setup.....	41
12.1.1	Purpose.....	41
12.1.2	Using this window	41
12.2	Changing How it's Done: Processing Options	43
12.2.1	Purpose.....	43
12.2.2	Using this window	45
13.	Classifying Ship Targets.....	46
13.1	The Classification Aid.....	46
13.1.1	Purpose.....	46
13.1.2	Using this window	46
14.	The Display Panel.....	48
14.1	Miscellaneous Functions.....	49

14.1.1	Zooming	49
14.1.2	Printing.....	50
15.	A Quick Tutorial	50
16.	References	51
Appendix A: 3-D Linear and Circular Motion		53
Appendix B: Raw Data File Formats		54
Appendix C: Units		55
Appendix D: Troubleshooting.....		56

Tables

Table 1: Information that can be saved and loaded.	17
Table 2: Available colour maps.	29
Table 3: Tape recorder button functions.	30
Table 4: Units used internally and in the graphical user interface.	55

Figures

Figure 1: Illustration of radar and target motion within the global coordinate system.	7
Figure 2: Definition of induced motions within the local coordinate system.	10
Figure 3: Definition of parameters for reading a portion of data from a file.	16
Figure 4: Radar signal processing steps.	18
Figure 5: Display processing steps.	19
Figure 6: The ISARLAB System.	20
Figure 7: The ISARLAB Setup window.	23
Figure 8: The Display Panel showing the File pull-down menu.	26
Figure 9: The Display Panel showing the Window pull-down menu.	27
Figure 10: The Display Panel showing the Display pull-down menu.	28
Figure 11: The Button Bar.	30
Figure 12: The Movie Options window.	31
Figure 13: The Display Panel showing the File Load pull-down menu.	32
Figure 14: The Load Matlab Data window used for file selection.	33
Figure 15: The Display Panel showing the File Import pull-down menu.	34
Figure 16: The Data Import file selection dialogue window and the Data Import window.	35
Figure 17: The Scenario Setup window and the same showing the Induced Motion menu.	37
Figure 18: The Position, Linear Motion and Circular Motion windows.	38
Figure 19: The Sinusoidal model Induced Motion window and the SMP File Choice window.	39
Figure 20: The Target induced motion graphic.	40
Figure 21: The Signal Setup window.	42
Figure 22: The Processing Options window.	43
Figure 23: The Classification Aid window.	47
Figure 24: The Display Panel.	49
Figure 25: Definition of parameters for circular motion.	53

1. Introduction

ISARLAB, which is an abbreviation of "Inverse Synthetic Aperture Radar Laboratory", is a suite of programs running under MATLAB® that has been designed to provide interactive visualisation of both simulated and experimental Inverse Synthetic Aperture Radar (ISAR) data.

Even though high-resolution radars are becoming more common, there is still a fundamental lack of access to real high-resolution radar data. Not everyone has access to an experimental radar and those who have are often involved in militarily sensitive radar cross section (RCS) research. The problem with collecting data in the field is that it costs both time and money. For the study of target classification using high-resolution radar, huge amounts of data are needed.

High-resolution radar simulators are scarce and building a new one from scratch is a formidable task. Choosing the modelling complexity of the simulator is a key decision that is dependent on the final application. For target detection, simulations based on a Swerling model may suffice. On the other hand, for target RCS modelling, it is always necessary to collect some real data. Simulators that address RCS calculation or prediction are computationally expensive and cumbersome to use, [1]-[3]. Other simulators that use simpler scattering models have been geared towards very specific problems [4], [5] and therefore lack the flexibility and extensibility required for different target types and encounter scenarios.

The purpose of ISARLAB is to generate high-resolution radar data that can be used for target classification studies. ISARLAB is NOT intended for RCS modelling or for studying radar backscatter from targets. These types of applications require a simulator with a detailed electromagnetic approach because the amplitude of the simulated returns must correspond very closely to the amplitude of the real returns. ISARLAB attempts to model the information relevant to the task of target classification. We made certain key assumptions about the level of simulation required for target classification studies and then designed ISARLAB so that these important features were modelled. The primary application for ISARLAB is to generate simulated data for target classification studies. Nevertheless, ISARLAB can also be used to conveniently browse experimental data.

This document is broken up into two basic parts. The first (Sections 3 to 7 and Appendices A to C) equates to a Reference Guide and the second (Sections 8 to 15 and Appendices D) equates to a User's Guide, both of which are usually delivered with a commercial software package. Prior to these an introduction to Inverse Synthetic Aperture Radar (ISAR) and radial motion compensation is given in Section 2.

2. Inverse Synthetic Aperture Radar (ISAR)

2.1 Basic ISAR Theory

Since the prospective users of this software will have had some exposure to ISAR imaging we shall not embark on a detailed description of the theory. Instead we will give a brief summary then concentrate on the characteristics particular to our radar systems and therefore the data we are able to process. In any case, there are many excellent references to this form of radar imaging, most of which can be found in or via the texts by Wehner [6] and Mensa [7].

The basic principle of ISAR imaging is to coherently collect the wideband echo signals that are produced as the object of interest rotates to present a change in viewing angle to the radar. Processing the individual wideband echo signals provides information as to the relative range of individual scatterers on the target. These range profiles¹ can be thought of as projections of the target's scattering centres onto the line-of-sight range vector from the radar and if the aspect angle of the target is known, some dimensions can be extracted. If the target is assumed to be rotating at a constant rate relative to the radar then Doppler spectral analysis of the time-history of range profiles can provide additional information about the target's scattering centres. This cross-range resolution is achieved because there is a velocity differential across the target caused by its rotation that manifests itself in the received signal as a Doppler frequency differential. By coherently measuring these signals over time, then performing a spectral analysis, the Doppler frequency content and therefore the relative position of scatterers can be determined. Since the location of target scatterers to within one range resolution cell has already been obtained in generating range profiles, this Doppler or cross-range processing makes it possible to separate scatterers that reside in the same range cell. The eventual result of these two distinct processing steps is a range versus cross-range map of the target's scattering centres, otherwise known as an ISAR image.

To assist in visualising the form of the ISAR image generated in a given scenario, it is useful to note that the projection plane is simply defined as being parallel to the radar line-of-sight and perpendicular to the effective rotation axis of the target. The term effective is used here because the target does not actually have to rotate but only appear to do so from the radar's point of view. An example of this is the situation of imaging an aircraft in level flight as it traverses the radar viewing area while being tracked by the radar antenna(s). Unfortunately, imaging in this scenario has other complications that will be addressed in the section on radial motion compensation (Section 2.2).

The resolution achievable in range, also referred to as slant-range resolution, is directly related to the unambiguously sampled bandwidth of the transmitted radar signal, in the case of coded waveforms (stepped-frequency, chirp, etc.), or the time delay

¹ Range profiles in this context are also often referred to as high range resolution (HRR) profiles.

sampling resolution, in the case of uncoded pulses. Specifically, slant-range resolution Δr_s is expressed by the approximate relationship

$$\Delta r_s \approx \frac{c}{2\beta}, \quad (1)$$

where β is the radar signal's bandwidth and c is the propagation velocity of the electromagnetic wave.

The data that is accepted by this toolbox is assumed to come from radars that use either stepped-frequency or linear FM (chirp) waveforms. A stepped-frequency waveform consists of transmitting a burst of narrowband pulses, whereby each pulse has a carrier frequency which is incremented from pulse to pulse. Processing this waveform requires conversion of echo data, collected in the frequency domain (one sample per frequency step), into synthetic range profiles. In essence, the frequency response of the target collected over some bandwidth is converted into an impulse response, with the process typically carried out using an inverse discrete Fourier transform (DFT⁻¹).

A linear frequency modulated (LFM) waveform consists of transmitting a relatively long frequency coded pulse covering the desired bandwidth. As the name implies an LFM pulse has a linear frequency versus delay relationship, or equivalently a quadratic phase variation with time. Processing is performed in a pulse compression receiver where the return pulse is matched filtered to produce a high-resolution target response or range profile. Matched filtering essentially convolves the target return pulse with the transmitted pulse to once again give an impulse response.

The advantage of an LFM waveform is that a high-resolution range profile can be obtained with a single pulse compared to the many pulses needed to cover the required bandwidth with a stepped-frequency waveform. However, a chirp radar requires a larger instantaneous bandwidth than a stepped-frequency radar, and are therefore more sophisticated to design and expensive to build.

The Doppler spectral analysis that results in cross-range target information is applied to each range resolution cell in the time-history of range profiles that result from range processing (pulse compression). Typically, the process is performed using a discrete Fourier transform (DFT). Cross-range resolution Δr_c will not be derived here but simply stated as

$$\Delta r_c = \frac{\lambda}{2\omega T} = \frac{\lambda}{2\Delta\theta}, \quad (2)$$

where λ is the radar signal wavelength, ω is the effective rotation rate of the target, T is the image integration time and $\Delta\theta$ is the effective aspect angle change. It is obvious from Equation (2) that in a non-cooperative target imaging situation, where the rotation rate of the target is unknown, the cross-range resolution and therefore the

cross-range scale on the ISAR image will also be unknown. This feature of ISAR imaging is a constant problem when it comes to interpreting a target image and is a continuing area of research.

In summary, the format of data used by ISARLAB is a 2-dimensional array. The first dimension is frequency in the form of complex samples (In-phase and Quadrature) of the target's frequency response and the second dimension is time. The data is organised as a matrix where each row represents one frequency sweep with the pulse frequency increasing from left to right (assuming an up-sweep in the case of a stepped-frequency waveform or an up-chirp in the case of an LFM waveform). The rows are placed in chronological order from top to bottom. The format of intermediate data matrices produced during processing is the same orientation as the raw data in that frequency samples will be converted to impulse response or range profile samples and time will be converted to Doppler frequency or cross-range. In some situations the data will have already been range compressed so it will enter ISARLAB in the same format as for the intermediate data matrices.

2.2 Radial Motion Compensation

The first problem that one encounters when attempting to image real-life radar targets is the presence of motions other than the rotational component required by the theory and therefore inherently assumed by the signal processing. The most significant motion in terms of its effect on image quality is the radial translation component. That is, the component of target motion that causes a change in radial distance between the radar and target during the image integration time. The major effect of radial motion is to shift the position in range of the target return from profile to profile, which results in a misalignment of data input to the Doppler spectral analysis. In other words, the Doppler frequencies that we are attempting to estimate are spread out over a number of range cells. Since the processing acts on range cells independently, there may be only a small portion of signal remaining in a particular cell, thereby causing a poor estimate of frequency by the frequency analysis. The result of this range walk, where scatterer returns effectively "walk" through range cells, is a smearing of the resulting image in the cross-range dimension. Naturally, the extent of the smearing is dependent on the amount of radial motion. For instance, the image produced by a large slow moving ship may suffer minimal distortion that only appears to decrease the effective resolution of the system. On the other hand, a jet fighter aircraft will almost certainly generate a very distorted image, if a recognisable target image is formed at all.

Range walk can be circumvented if the radar uses a narrow uncoded pulse by employing a system that tracks a single prominent scatterer in the target return and places that sample into the same resolution cell for each range profile recorded. However, for coded waveforms such as stepped-frequency and chirp pulse compression, sampling occurs before there is a range profile available for tracking. Consequently, the sample position bears no relationship to the position within the

resulting synthetic range profile. Correction for target radial motion is therefore required after sampling as part of the signal processing.

The radial motion compensation algorithm implemented in this toolbox is similar to the methods used by Chen and Andrews [8] and Wehner [6], in that it is also a two-stage process. The first step sets up a rough alignment of the data from profile to profile by removing the phase changes that cause a scatterer at a given cross-range position to "walk" out of the range cell in which Doppler processing is being carried out. The second step performs fine alignment to account for residual phase changes caused by movement in range that exceeds a small fraction of a wavelength. A detailed description of the radial motion compensation algorithm will not be recounted here since it can be found in Haywood and Evans [9]. As a final remark, the type of radial motion compensation used here is sometimes referred to as *hot-spot tracking*, since both stages of the algorithm effectively track one or more prominent, although not necessarily the same, target scatterers.

3. The ISARLAB Model

ISARLAB can process and display both simulated data or stored data collected from experimental trials. When simulating and then processing data ISARLAB is said to be in **simulation** mode and when processing experimental data it is said to be in **Trials** mode.

In simulation mode, ISARLAB models a radar illuminating a target with one of a number of predefined waveforms or, if preferred, a user defined waveform. ISARLAB caters for the two most commonly used wideband radar signals, namely stepped frequency and linear FM (chirp). It is relatively easy to incorporate other waveforms, by writing code with a simple parameter interface.

The radar and target can be either stationary, moving linearly or moving in a circle. This type of motion, which we call gross motion, is defined relative to a global coordinate system in which the radar and target are considered to be moving points. This is illustrated in Figure 1 where the radar platform is airborne with a circular trajectory and imaging a ship target with a linear motion. The radar and the target positions and gross motion are measured in the global coordinate system. The target's scatterer positions and its induced motion are measured in the local coordinate system.

The target being illuminated is assumed to be rigid and made of a finite number of discrete scatterers undergoing rotations about the origin of a local coordinate system. These rotations are called induced motion and are due to the forces applied on ship targets by the sea and to a lesser extent on airborne targets by the atmosphere.

The two coordinate systems are related by the convention that the target's location in the global coordinate system is the origin of the local system. They are also related in

that the velocity vector of the target in the global system coincides with the x-axis of the local system. Both coordinate systems are right-handed.

The simulated backscatter of the target from the radar in this scenario is then processed by selecting from a number of available signal processing algorithms. A variety of display formats and options are also available.

The use of the terms "radar" and "target" were adopted to keep the system general, in the following sense. The platform could be an aircraft, ship, or based on land, or even transported in an automobile. Similarly, the target can be anything that can be represented by a number of scatterers. This includes aircraft, ships, land-based vehicles or even man made structures such as buildings. The illustrations in this document which portray airborne imaging of ship targets are not intended to imply any limitations in this sense.

ISARLAB, in trials mode, reads previously stored radar returns from experimental trials in any of several supported formats, then processes and displays this data using the same code used to process the simulated backscatter.

The system is written in the MATLAB language and runs under version 5.0 or later. MATLAB is supported on a number of computer platforms, which makes ISARLAB portable by default. ISARLAB is driven by a graphical user interface that is used to define new, or read in pre-defined information. This information includes radar waveforms, target reflectivity models, radar motions and target motions. The processing and displaying selections are also made using the interface. For more information on use of the graphical interface see Sections 8 to 15.

3.1 Modelling Radar and Target Motion

Motion has been modelled on two scales. An independent coordinate system is associated with each scale. Gross motion views the radar platform and target as points moving in 3-D space with positions relative to the global coordinate system. On a finer scale, the target also has an optional induced motion, which is a pseudo-periodic motion due to the forces applied by the sea on boats and ships and, to a lesser extent, forces applied by the air on aircraft. Induced motion modifies the positions of the individual scatterers with respect to the local coordinate system. The two coordinate systems are related as described in Figure 1. Induced motion is illustrated in Figure 2. As a final step, target alignment, described in Section 3.1.3, is performed after gross and induced motion calculations. The motion updates of the radar platform and target are implemented sequentially in the following predefined order:

1. Update gross motion of radar
2. Update gross motion of target
3. Update induced motion of target
4. Align target orientation

3.1.1 Gross Motion

In general, both the radar platform and the target of interest can have quite arbitrary trajectories. To simplify motion modelling, we limit radar and target motion to simple trajectories. These trajectories are parameterised by 3-D vectors consisting of:

1. an instantaneous position, velocity and (constant) acceleration, or
2. an instantaneous position, a centre of rotation and a rotation axis vector (direction and rotation rate).

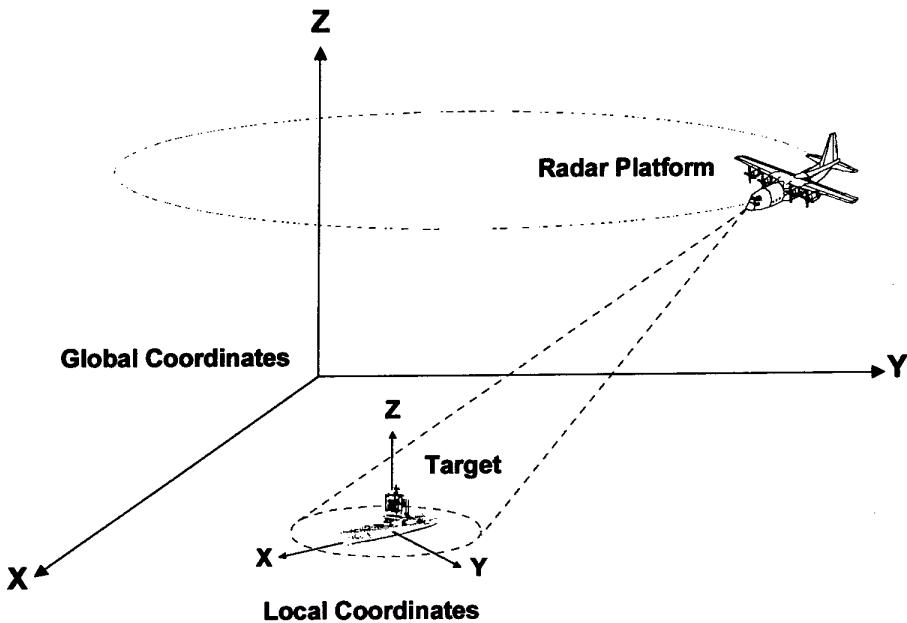


Figure 1: Illustration of radar and target motion within the global coordinate system.

The first trajectory is called linear motion and the second circular motion. Collectively we refer to these trajectories as gross motion. Both the radar's and target's gross motion are represented by a single point moving with respect to the global coordinate system.

As well as linear and circular motion, a special case of linear motion has been added for convenience. It is called stationary "motion", which as the name implies is a specification of a position only (with velocity and acceleration being set to zero).

The equations of motion which define how each new position can be calculated from the old position and the motion vectors are described in Appendix A: 3-D Linear and Circular Motion.

Rather than specifying 3-D vectors, it is easier to visualise, easier to describe and more common to encounter situations that can be described using the following quantities (the names below correspond to those seen in the ISARLAB software):

1. For linear motion:

- X position (m)
- Y position (m)
- altitude (m)
- heading (degrees)
- velocity (ms^{-1})
- acceleration (ms^{-2})
- climb rate (ms^{-1})

X position, Y position and altitude; together constitute the 3-D position in the global coordinate system. Heading is measured parallel to the X-Y plane. Zero (0) degrees is defined to be the same direction as the X-axis and heading increases positively in a clockwise direction looking along the Z-axis towards the origin. Velocity and acceleration are scalar quantities and both apply in the direction specified by heading. The climb rate is the velocity in the Z-axis direction. Velocity and acceleration are with respect to the ground and not the air or sea.

2. For circular motion:

- X position (m)
- Y position (m)
- X position of centre (m)
- Y position of centre (m)
- altitude (m)
- speed (ms^{-1})

X position and Y position define the position on the circumference of a circle centred at X position of centre and Y position of centre. The circle is parallel to the X-Y plane and hence the altitude applies to both the position and position centre. The motion about this circle is anticlockwise if speed is positive and clockwise if speed is negative. Speed is the magnitude of the instantaneous tangential velocity and is proportional to the rate of rotation. Speed is with respect to the ground and not the air or sea.

In our implementation of gross motion, we translate either the linear or circular quantities into an augmented array of three 3-D vectors that are interpreted differently according to the context of linear or circular motion. These arrays (shown below) are our representation of the radar's or target's gross motion.

The format for linear motion is:

$$Linear = \begin{bmatrix} P_x & P_y & P_z \\ V_x & V_y & V_z \\ A_x & A_y & A_z \end{bmatrix} \quad (3)$$

where:

P_x, P_y, P_z - are the position coordinates of the radar or target (m)

V_x, V_y, V_z - is the velocity vector of the radar or target ($m s^{-1}$)

A_x, A_y, A_z - is the acceleration vector of the radar or target ($m s^{-2}$)

For circular motion, the format is:

$$Circular = \begin{bmatrix} P_x & P_y & P_z \\ C_x & C_y & C_z \\ N_x & N_y & N_z \end{bmatrix} \quad (4)$$

where:

P_x, P_y, P_z - are the position coordinates of the radar or target (m)

C_x, C_y, C_z - are the position coordinates of the centre of rotation (m)

N_x, N_y, N_z - is the axis of rotation (radians s^{-1})

The magnitude of the axis of rotation equals the rotation rate and its direction specifies the direction of the rotation based on the "right hand rule".

For a stationary radar or target the format of the gross motion array is:

$$Stationary = \begin{bmatrix} P_x & P_y & P_z \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (5)$$

where:

P_x, P_y, P_z - are the position coordinates of the radar or target (m)

3.1.2 Induced Motion

In addition to gross motion, the target may have a motion induced by the medium through which it moves. This is most pronounced in seagoing vessels but is also seen to a lesser extent in aircraft. In general, 6 degrees of freedom can be used to describe an object's induced motion, and these can be separated into 3 linear components (surge, heave and sway) and 3 rotational components (roll, pitch and yaw). Since only the rotational components have a significant effect on the formation of ISAR images, the linear components are not simulated.

Induced motion is therefore implemented as rotations applied to the scatterer positions, which are defined in the local coordinate system xyz. These rotations simulate actual roll, pitch and yaw. They are defined by anticlockwise rotations about the x, y and z-axes respectively, where the sense is determined by looking along the axes towards the origin. Figure 2 graphically depicts this convention. As rotations only commute (approximately) with small angles, the induced rotation is achieved by updating scatterer positions over small time intervals. The new positions are stored so they can be updated (again incrementally) at the next iteration. The positions together with the *Motion* matrix (Eqn 6) are a representation of the target's current state of induced motion.

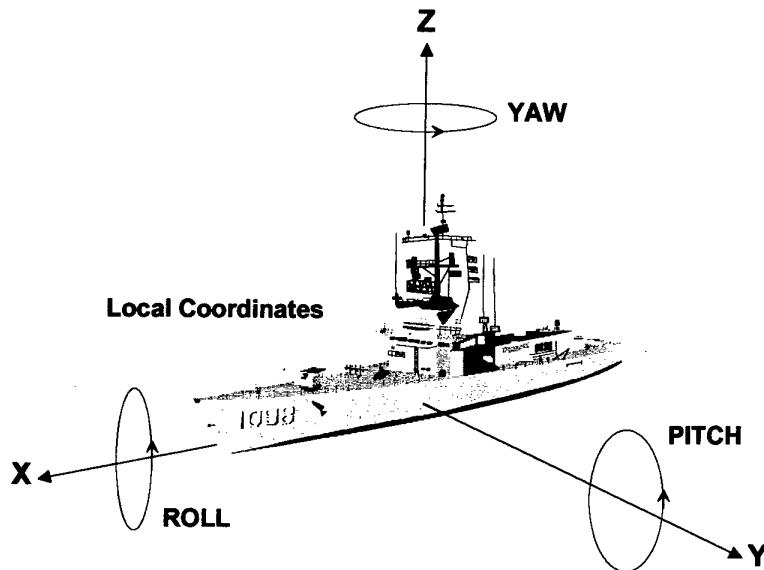


Figure 2: Definition of induced motions within the local coordinate system.

Induced motion can be specified in two ways. It can be specified crudely by giving the amplitude, period and phase of independent sinusoids that represent roll, pitch and yaw (as shown below) or more realistically it can be specified using pre-calculated and stored sets of roll, pitch and yaw angles that can be read from a file. An example of pre-calculated values is the result from a detailed ship motion modelling program [4].

If the former method is used, the array of parameters describing the induced target motion is:

$$Motion = \begin{bmatrix} A_r & T_r & P_r \\ A_p & T_p & P_p \\ A_y & T_y & P_y \end{bmatrix} \quad (6)$$

where:

- A_r, T_r, P_r - is the amplitude, period and initial phase for the roll angles
- A_p, T_p, P_p - is the amplitude, period and initial phase for the pitch angles
- A_y, T_y, P_y - is the amplitude, period and initial phase for the yaw angles

Roll is defined to be rotation about the x-axis, pitch is rotation about the y-axis and yaw is rotation about the z-axis. Amplitudes and phases are entered as degrees but stored as radians and periods are in seconds.

3.1.3 Target Alignment

Target alignment refers to the alignment of the local coordinate system with the target velocity vector, as measured in the global system. If this is not done, unrealistic situations such as the target moving "sideways" may arise. The convention we follow is that the local x-axis represents the "forward" direction for the target, hence we align the local x-axis with the target's velocity vector. A copy of the scatterer positions is maintained and target alignment is applied to this copy.

3.2 Modelling Radar backscatter

Radar backscattering from targets can be categorised into 4 main mechanisms:

1. Direct illumination specular scattering normal to surfaces or edges.
2. Diffractive scattering from edges and surface discontinuities.
3. Travelling wave scattering along edges.
4. Indirect (multiple) specular scattering from structures or cavities.

Normally the specular and diffractive mechanisms account for the majority of the radar backscatter. Specular backscatter is normally much larger than its diffractive counterpart. Travelling waves are important at long wavelengths. For the X-band frequencies (8-10 GHz) considered here, travelling wave backscatter is therefore not important. Backscatter due to multiple specular reflections is common for complex faceted structures such as ships, but less frequent for the smooth surfaces typical of aircraft. Multiple specular scattering from cavities occurs infrequently. It is also difficult to determine when this sort of backscatter is occurring.

The assumptions on which we base our target scattering model are as follows:

1. The target is rigid bodied with no rotating parts or engine cavities.
2. Since we are modelling in the high frequency (Fresnel) region, the target is represented as a finite number of discrete scatterers in 3-D space.
3. We assume the scatterer positions are more important for classification than their respective amplitudes. This does not mean that we fail to model relative amplitude differences between scatterers but that the exact level of the backscatter amplitude is not critical to our modelling.

4. Target classification will be made on the basis of major target scatterers hence modelling minor target features is lower priority.

We supplement these assumptions with the following conventions:

1. The positions of the target scatterers are defined with respect to a local coordinate system xyz. The origin of this local system is referred to as the position of the target or the target's origin in the global coordinate system XYZ. Ideally the target origin should correspond to the effective center of rotation of the target with respect to the radar. If this is not the case, then the Doppler returns from the target will be shifted. (This is not a critical issue because in real target imaging the apparent centre of rotation will normally shift during the course of relative motion).
2. The scatterer positions should be defined so that the target is "forward" along the x-axis and that the target is "level" in the x-y plane. This information is used in realigning the orientation of the target as its velocity changes direction and to define the state of equilibrium about which the induced motion applies. See Section 3.1 for more information about target alignment.

3.2.1 The Target Scatterer Model

The above assumptions were implemented by modelling the target scatterers as a set of points such that for each scatterer we have defined:

- x-coordinate position (m);
- y-coordinate position (m);
- z-coordinate position (m); and
- reflectivity or radar cross-section (dBsm).

Since target scattering is heavily dependent on the aspect angle at which the radar illuminates the target, it was necessary to allow a separate point scatterers' model for each angle in a range of aspect angles. Consequently, the whole model is composed of a 2-D array of points with one dimension being the set of points (position and reflectivity) defining the target scattering at a particular aspect angle and the other dimension being all the valid aspect angles for which there are corresponding models. Aspect angle is actually composed of two components, azimuth and elevation, but to simplify the modelling we consider aspect angle to be synonymous with azimuth angle. It is therefore assumed that one would need a different target model for each elevation angle to be simulated. Since scattering does not change significantly with the small changes in elevation, one model will usually suffice for a broad range of scenarios.

Aspect angle (azimuth) is by convention measured from the target to the radar in the X-Y plane of the global coordinates and in a clockwise sense from the forward direction of the target. For example, an aspect of 90° means the target is illuminated on its starboard broadside. Therefore, to incorporate all possible radar-target

geometries, the target model must cover a full 360° of aspect angles. However, this can be broken up into angular increments as fine as is deemed necessary to model real scattering variations.

ISARLAB uses the scatterer model by determining the aspect angle being simulated in a given scenario and selecting the list of point scatterers at the nearest corresponding aspect. Gross motions and induced motions are then imparted on the target scatterers before the received signal is generated. This is done by effectively convolving the impulse response for each scatterer with the transmitted signal then summing coherently. This procedure is further described in Section 4.1. Therefore, as the scenario changes, so does the set of point scatterers selected to represent the target.

3.3 Modelling the Radar Signal Waveform

The two most common high bandwidth waveforms used in high-resolution radars are stepped frequency and linear frequency modulation (chirp). ISARLAB accommodates both of these waveforms as well as a "pseudo" waveform called compressed linear frequency modulation. This is a special case of chirp where the pulse compression has already been performed. An example of this for a real radar occurs where pulse compression is done passively in a SAW compressor before A/D sampling. The parameters required for each waveform are listed below. Note that in the case of the stepped frequency waveform, the bandwidth is termed effective because it is synthesised from a number of discrete frequencies. The term burst refers to the transmission of a series of discrete frequency pulses. The sampling frequency is the rate at which pulses in this burst are transmitted (i.e. the real PRF). For more background on radar waveforms see Wehner [6].

The calculations that simulate the generation of the raw radar signals proceed on a single range profile basis. This means there is no relative motion during the collection of the data required in forming a range profile. A chirp radar only requires a single pulse to form a range profile, so the target and radar positions are updated after every pulse. A stepped frequency radar requires a burst of pulses to form a range profile, therefore the target and radar positions are updated after each burst. The onus is on the user to ensure relative motion during the stepped frequency burst time is not significant in the imaging scenario being simulated. In real-life imaging scenarios this calculation must also be done to ensure that minimal distortion is achieved.

Parameters for a stepped frequency waveform are:

- Centre frequency (Hz);
- Effective bandwidth (Hz);
- Pulse width (seconds);
- Effective pulse repetition frequency (Hz);
- Sampling frequency (Hz);

- Number of frequency samples per burst;
- Number of bursts per ISAR image; and
- Signal to noise ratio (dB).

Parameters for a chirp waveform are:

- Centre frequency (Hz);
- Chirp bandwidth (Hz);
- Pulse duration (seconds);
- Pulse repetition frequency (Hz);
- A/D sampling frequency (Hz);
- Number of A/D samples per pulse;
- Number of pulses per ISAR image; and
- Signal to noise ratio (dB).

Note that in Trial mode the signal to noise ratio is undefined and therefore not used.

Our implementation employs an enumerated data type called Radar Waveform that gives the context in which to interpret the Signal Waveform array for different waveforms. The parameters in this array are listed below and are interpreted as the corresponding parameters above.

- Radar Waveform type;
- Centre frequency (stored as Hz, entered as GHz);
- Frequency bandwidth (stored as Hz, entered as MHz);
- Pulse width or duration (stored as seconds, entered as microseconds);
- Pulse or burst repetition frequency (Hz);
- Sampling frequency (stored as Hz, entered as kHz);
- Number of samples per pulse/burst;
- Number of pulses/bursts per image; and
- Signal to noise ratio (dB).

4. Getting Data and Information

Now that the model has been described and some terminology has been introduced, we can describe in more detail the three main parts of the ISARLAB system.

The first part, used in simulations, is to define an instance of the model (see below) and to use this to generate radar returns. Alternatively, in trial mode data is not

generated, but is instead read from files of stored radar returns. The first part is described in this section. The other two parts, processing the radar returns into an image and displaying the image are described in Section 5 "Radar Signal Processing" and Section 6 "Display Processing", respectively.

The facilities available in ISARLAB for saving and loading information are described in this section.

4.1 Simulating Radar Returns

For simulation, the graphical user interface is used to define the:

- gross radar motion;
- gross target motion;
- induced target motion;
- target scatterers; and
- radar signal waveform,

which together comprise an instance of the ISARLAB model.

All of these components have been described earlier in some detail. Of these only the induced target motion is optional. If not defined, the system defaults to "no induced motion". Using this information the radar returns for the given model can be generated as follows.

The simulation defines the transmitted signal at frequency f and time t as

$$\exp(j 2\pi f t) \quad (7)$$

and the received signal from a number of scatterers as

$$\sum_k A_k \exp(j 2\pi f (t - \tau_k)) \quad (8)$$

where τ_k is the two-way time delay to the k^{th} scatterer, with k ranging from 1 to the total number of scatterers, and A_k is the reflectivity of each scatterer.

When demodulated we have

$$\sum_k A_k \exp(j 2\pi f \tau_k) \quad (9)$$

which yields the amplitude and phase change from transmitted to received signals.

The next stage is the signal processing of these simulated radar returns (Section 5).

4.2 Reading a Raw File of Radar Returns

We can also use the graphical user interface when processing data from experimental trials. It is used to specify the name and format of the file containing the stored radar returns and to specify the location and quantity of data to be read. Figure 3 shows how to specify which rectangular block of stored radar returns to read. In this illustration the file is made up of stepped frequency data, but the same principle applies to data that has already been range compressed. Uncompressed chirp data however, would require all the samples for a pulse to be read for successful range compression. Reading localised data segments is necessary as memory limitations of computer hardware means that the system can often not accommodate the massive amounts of data that are typically collected on trials. This segment of data is converted from binary format to complex numbers and then read into memory for use by ISARLAB. Also, if a file header is available, the information it contains can be used to automatically specify the signal waveform.

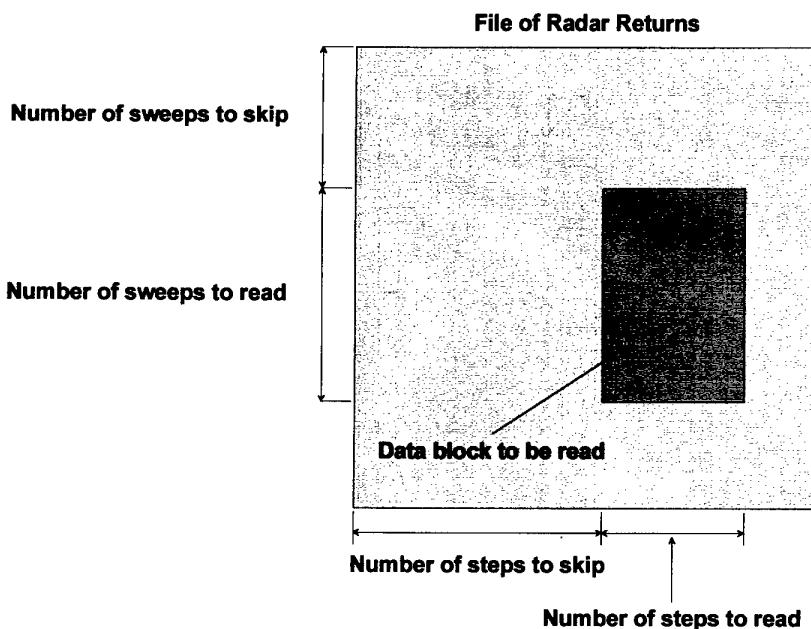


Figure 3: Definition of parameters for reading a portion of data from a file.

4.3 Saving and Loading Information

Information entered or selected by the user, such as gross motion of radar and target, induced motion of target, signal parameters, and signal and display processing options, can be saved, then loaded at a later time. The user then becomes more efficient because they,

1. save time by not repeatedly entering the specifications that created them;
2. save time by not needing to wait for them to be recreated;
3. do not need to remember them or note them somewhere outside the system; and
4. can give meaningful names to the information saved and form logical sets of information that can be stored with the data (e.g. in the same directory).

Table 1 summarises the information that can be saved and loaded.

Table 1: Information that can be saved and loaded.

Mode	Information	Variables Involved	Comments
Simulation	Data Signal Scatterer Model Scenario Movie User Selections	<i>filedata, tx</i> <i>signal</i> <i>scats</i> <i>radar, target, motion</i> <i>M</i> <i>userseln</i>	Save Only (<i>tx</i> only saved for linear FM waveform) Load Only Can be a large file An array that holds all display and processing selection
Trial	Data Signal Movie User Selections	<i>filedata, tx</i> <i>signal</i> <i>M</i> <i>userseln</i>	<i>tx</i> only loaded for linear FM As for Simulation As for Simulation

Note that in Simulation mode with a linear FM waveform a replica of the transmitted signal *tx* is generated for the matched filter range compression process. This variable is always saved automatically with the data so that the two remain associated when the simulated data is loaded in Trial mode for re-processing and display.

5. Radar Signal Processing

ISARLAB can perform various types of radar signal processing. The processing is broken into modular sections so that new processing algorithms can be easily incorporated (these are summarised in Figure 4). The signal processing discussed here is performed after the generation of the signals returned from the target models, and results in the production of 1-D range profiles or 2-D ISAR images. Division of the signal processing in this way allows ISARLAB to process experimentally collected radar data as well as simulated data.

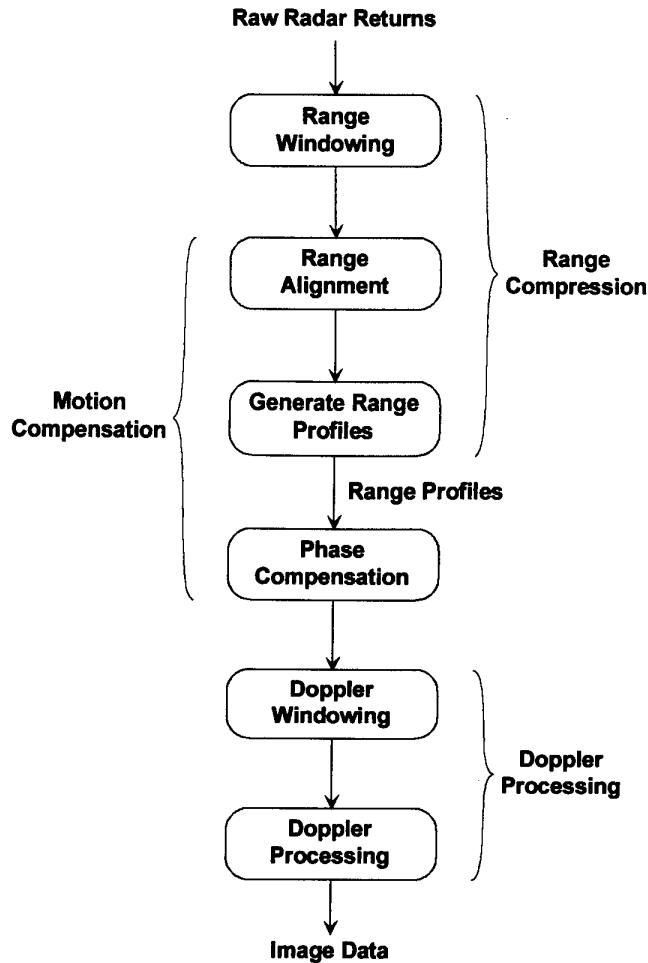


Figure 4: Radar signal processing steps.

The processing of the return signal is achieved in three steps. The first step, called range processing or range compression, essentially deconvolves the return signal using knowledge of the transmitted signal. This provides the impulse response of the target (range profile). The second step is radial motion compensation that attempts to remove the relative radial movement between the radar and target. A number of phase compensation algorithms are supported by ISARLAB [9]-[11]. The third and final step in the ISAR image production is Doppler processing. Here a spectral analysis is performed in each range resolution cell to estimate the distribution of Doppler frequencies and hence the cross-range positions of target scatterers. Various signal processing windows can be applied before both the range and Doppler processing stages [12].

6. Display Processing

Display processing is performed in four steps. These are illustrated in Figure 5.

First, the data output from the signal processing stage is converted to decibels (dB). This change from a linear scale to a logarithmic scale makes a large dynamic range easier to visualise. This results in more detail being apparent in the final image.

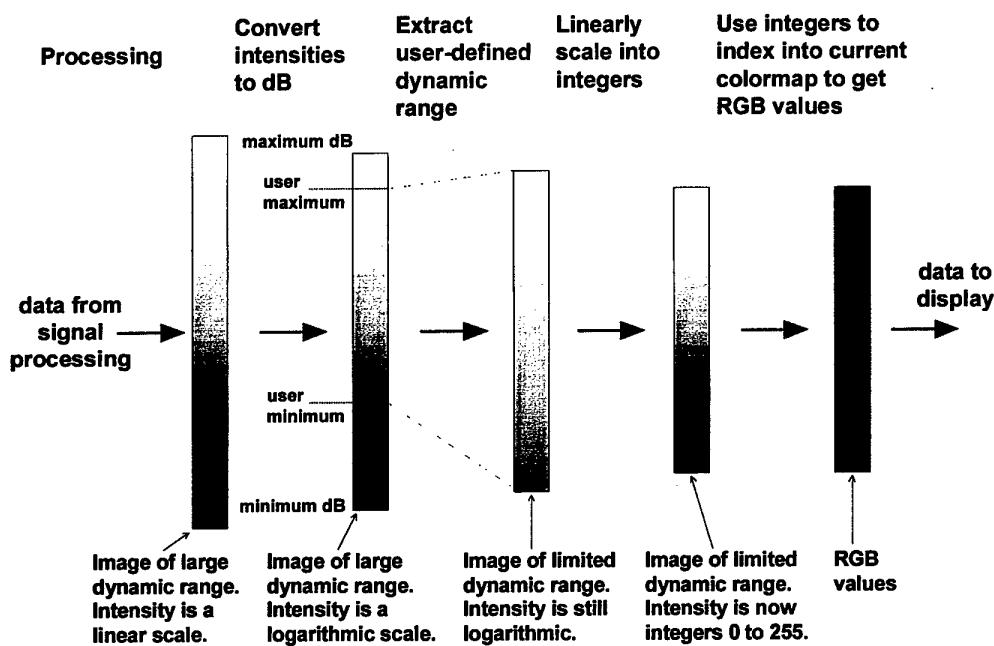


Figure 5: Display processing steps.

Next, a subset of the dynamic range is selected from the data for closer inspection. This is necessary because the dynamic range of the display device is much less than that of the radar data. Values outside of this range are clipped. If the range starts from the maximum intensity image pixel, which is arbitrarily set to zero, then this is called autoscaling. Autoscaling is the default supported by ISARLAB. Alternatively, a maximum intensity (in dB) can be specified and clipping occurs above this maximum and under the dynamic range below this maximum.

The next step is to linearly map these intensities (which are real numbers) into the range of integers that index the current colormap. The current colormap is the set of Red, Green and Blue (RGB) values that are stored in an array into which the integers will index. There are a number of colormaps that are available. More information on colormaps is available in Section 9.1.4.2.

Finally these numbers are the values that MATLAB uses to display the ISAR image. There are currently two representations of the ISAR image, namely a MATLAB surface plot and a MATLAB image plot. Both are intensity maps but have different properties that are described in Section 9.1.4.1. In later versions it is anticipated that a number of other representations of the final image could be available, e.g. waterfall plots, contour plots, etc.

7. System Description

Each of the previous sections described a particular component of ISARLAB. It is now appropriate to show how these components are combined to form an integrated system. A data flow diagram describing the ISARLAB system at the module level is shown in Figure 6. This graphic also shows how processing in the ISARLAB system can be separated into three stages:

1. Generating Simulated Data or Reading Stored Data;
2. Signal Processing; and
3. Displaying the Processed Data.

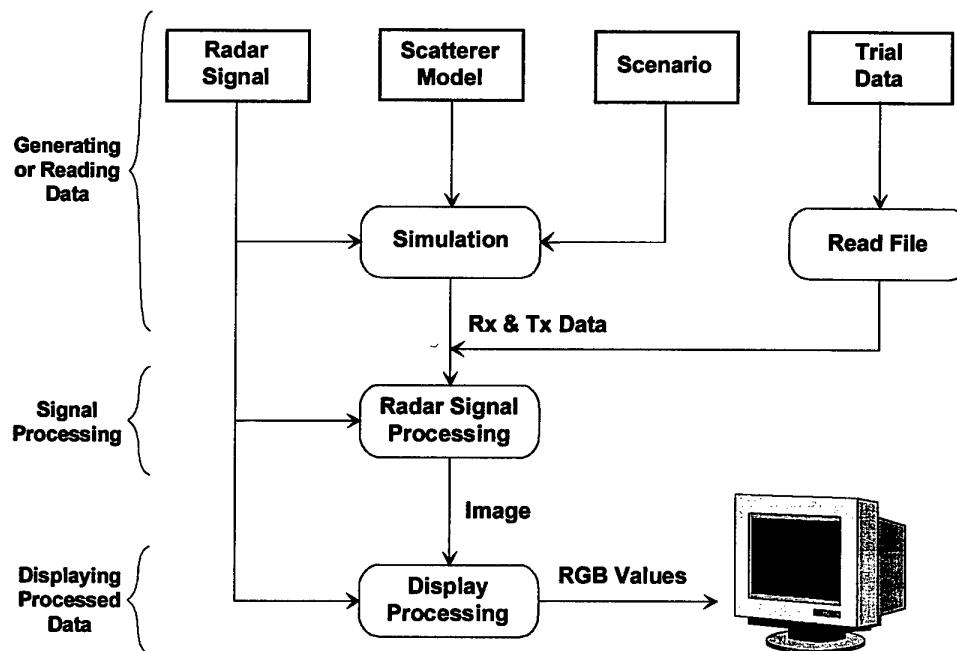


Figure 6: The ISARLAB System.

To further assist in understanding how all the components fit together, a high-level pseudo code summary of the ISARLAB system is presented below.

```

{initialisation}
if SIMULATION
    define radar,target,induced_motion,scatsmodel,signal
else
    define signal
    filedata = readfile(filename,fileformat)
end
{end initialisation}

{main program}.
if SIMULATION
    while PLAYING
        [rx,tx,radar,target,scats,induced_motion] = ...
            radsim(signal,radar,target,scatsmodel,scats,induced_motion)
        image = isar_process(rx,tx,signal)
        show_imag(image,signal,output_format)
    end
else
    while PLAYING and not END_OF_DATA
        [rx,tx,image_no] = get_next_block(filedata,image_no)
        image = isar_process(rx,tx,signal)
        show_image(image,signal,output_format)
        image_no = image_no + 1;
    end
end
if RECORDING
    movie = append(picture,movie,frame)
end
{end main program}

{radsim}
for k = 1 to number_of_pulses
    if sf_waveform
        [rx,tx] = simulate_sfdata(time_inc,signal,radar,target,scats_posns)
    elseif lfm_waveform
        [rx,tx] = simulate_lfmdata(time_inc,signal,radar,target,scats_posns)
    end
    radar = update_global_motion(radar)
    target = update_global_motion(target)
    [scats,induced_motion] = update_induced_motion(scats,induced_motion)
    scats_posns = update_orientation(scats,target_velocity)
end
scats = calc_reflectivity(scatsmodel,scats,radar_posn,target_posn)
{end radsim}

{simulate_sfdata}
dt = burst_repetition_interval {from signal information}
delays = calculate_delays(dt,scats_posn,target_posn,radar_posn)
generate transmitted sf signal
generate received sf signal
{end simulate_sfdata}

```

```
{simulate_lfmdata}
dt = pulse_repetition_interval {from signal information}
delays = calculate_delays(dt,scats_posn,target_posn,radar_posn)
generate transmitted lfm signal
generate received lfm signal
{end simulate_lfmdata}
```

8. Introduction to Using ISARLAB

8.1 Installing ISARLAB

ISARLAB is a computer program consisting of a set of functions (called M-files) that are written in the MATLAB language. Such a set of M-files is often called a toolbox. Instructions for installing ISARLAB and for installing toolboxes in general can be found in the *Installing Additional Toolboxes* section of the MATLAB *Installation Guide for UNIX* [13], or *Installation Guide for PC and Macintosh* [14].

ISARLAB has been designed to work in conjunction with the ISAR toolbox, which contains the necessary radar signal processing algorithms. More information about this set of functions can be found in the *ISAR Image Processing Toolbox User's Guide* [15]. To function, the ISAR toolbox in turn needs MATLAB's *Signal Processing Toolbox* [16].

It is recommended that the ISAR and ISARLAB toolboxes be placed in separate directories under \$MATLAB/toolbox/. However, regardless of where the toolboxes are kept, paths to the location of these and other files required by ISARLAB can be defined using a *setup* utility. This function (type *setup_il* at the MATLAB command line prompt) should be run prior to running ISARLAB for the first time. The **ISARLAB Setup** window will then appear (Figure 7), from which a range of options and parameters can be set by pressing the appropriate button and editing the choices in the corresponding window that appears. In each case the **Save ...** button needs to be pressed to save the corresponding set of chosen options, parameters, etc. Finally, the user should set up a MATLAB path pointing to the ISARLAB toolbox so that the application can be run from any current directory.

ISARLAB has been designed to run on any of the many platforms that MATLAB supports. It has been tested on UNIX systems (SUN SPARCstations and DECstations) and IBM compatible PCs. To work on other platforms minor modifications may need to be made. For example, window sizes may need to be adjusted to suit the often-smaller screen displays associated with some PCs or minor code changes may be needed to accommodate minor MATLAB language aberrations between platforms. The graphical user interface widgets or controls (Section 8.2.2) may also appear and work slightly differently between platforms.

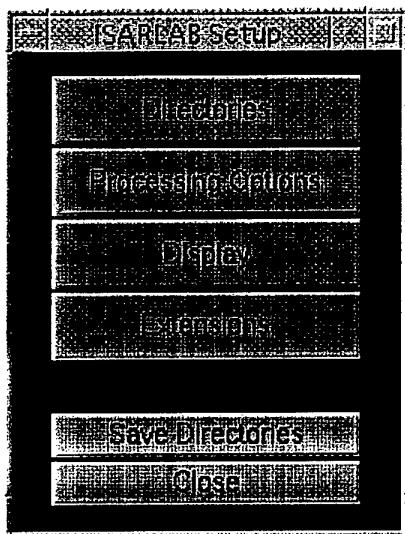


Figure 7: The ISARLAB Setup window.

8.2 Using ISARLAB

8.2.1 Starting ISARLAB

Starting ISARLAB involves just two basic steps. The first step is dependent on the computer platform you are using and should be done after consulting your MATLAB documentation if you are unfamiliar with MATLAB. The second step runs ISARLAB.

1. At the command line prompt start up MATLAB.
2. Within MATLAB type: **isarlab**
3. If desired, change to a working directory that has or will have data and information files (Section 8.2.4 explains this further).

8.2.2 The Graphical User Interface

ISARLAB has a Graphical User Interface (GUI) for ease of use. This means that the mouse is used extensively to manipulate regions on the screen called *controls*. Examples of controls are popup menus, push buttons, radio buttons and editable text. The MATLAB manual called *Building GUIs with MATLAB* [17] describes the appearance and use of these and other controls, as well as how to create them and designing them into a layout.

8.2.3 User Input

Note that most input is driven by the mouse but occasionally it is necessary (and is easier) to type in a number or name. Names are only used for files (see Section 8.2.4). Numbers can be any valid numeric MATLAB expression. Examples of valid numeric expressions are:

- 20
- 5.12e7
- `exp(i * pi)`
- `round(128 * rand - 64)`

Names or numeric expressions are entered in editable text controls and if numeric data is expected and non-numeric data is entered the system "crashes" and a fatal message is displayed. If a name is expected and an invalid name is entered, in general an informative message is displayed and the user can try again. The context of the information to be entered should make it clear whether a number or name is required.

8.2.4 Stored Information and Filenames

ISARLAB stores or loads information and reads data from files that are usually organised into directories. Files have associated names that vary in format between computing platforms. Consult your system administrator or operating system manual if unsure what constitutes valid names, or what makes up a file or directory. It is recommended that related files all coexist in the same directory, which you can change to before reading, saving or loading (see Sections 10.1, 10.2 and 11.1 for full descriptions of these functions).

A filename of raw data or ISARLAB information can be entered in the editable text areas of some windows. Include full paths in the name if you are not in the same directory as the information. If an asterisk is in any part of the filename, a new window appears that allows you to navigate about the file system with the mouse and to select a filename. Once the filename is selected, the new window will disappear and the selected name will replace the typed name containing the asterisk.

The term raw data refers to radar returns in binary format. Information, in contrast, is output generated by ISARLAB such as stored user selections, an animated movie or binary data converted to complex matrices. This information is saved in MATLAB's special mat-file format. This use of files means that only valid filenames (for the particular computing environment on which ISARLAB is being run) can be used to save and load information. The filenames will by default have a '.mat' ending or extension but this is entered optionally by the user.

More information on the contents of the information files can be found in Section 4.3.

8.2.5 Prompts and Messages

In keeping with MATLAB standards, messages are displayed in the command window (i.e. the window that has the interactive MATLAB prompt). There are three types of messages. Informative messages are those that are meant to make the user aware of the state of the system, for example the fact that an operation is in progress or has completed successfully. Diagnostic or Warning messages are those that

describe the unexpected situation that has occurred, such as data to be expected in a file was not found or that selected or entered values are not valid. Fatal messages are rare and occur in exceptional circumstances such as entering a non-numeric MATLAB expression in a numeric field. Numeric expressions are described in Section 8.2.3.

In general, all but fatal messages are recoverable. Fatal messages can be recognised by the leading '???' characters before the message. ISARLAB will often work even after a fatal condition has occurred, but if problems persist then it is recommended to exit ISARLAB and start again. Memory limitation problems are the most likely cause for needing to restart the program.

8.2.6 Exiting ISARLAB

When finishing an ISARLAB session, exit by selecting the `Exit` item on the `File` menu in the `Display Panel` window (Figure 8). This should clear all ISARLAB windows and leave you at the MATLAB prompt. To exit MATLAB itself, simply type `quit`.

9. Navigating ISARLAB

9.1 The Display Panel

9.1.1 Purpose

ISARLAB was designed to be functionally modular, which means that each component is independent of any other, although they can communicate by passing parameters, etc. The `Display Panel` (Figure 8), in addition to being where data (i.e. range profiles, images, etc.) are displayed, is in fact the main control panel for ISARLAB. Command of ISARLAB and access to all the user-defined components is achieved via a number of pull-down menus located along the top of the `Display Panel`. These menus are briefly outlined below and further details can be found in a corresponding section of this document.

9.1.2 File menu

As the name implies, this menu provides a way of accessing files containing the information ISARLAB needs to function. Although most of this information (excluding experimental trial data) can be generated internally, the file facility allows it to be saved and loaded quickly and efficiently.

9.1.2.1 Mode menu

This two-item menu allows switching between the `Trial` and `Simulation` modes of ISARLAB. Both modes are described throughout this manual.

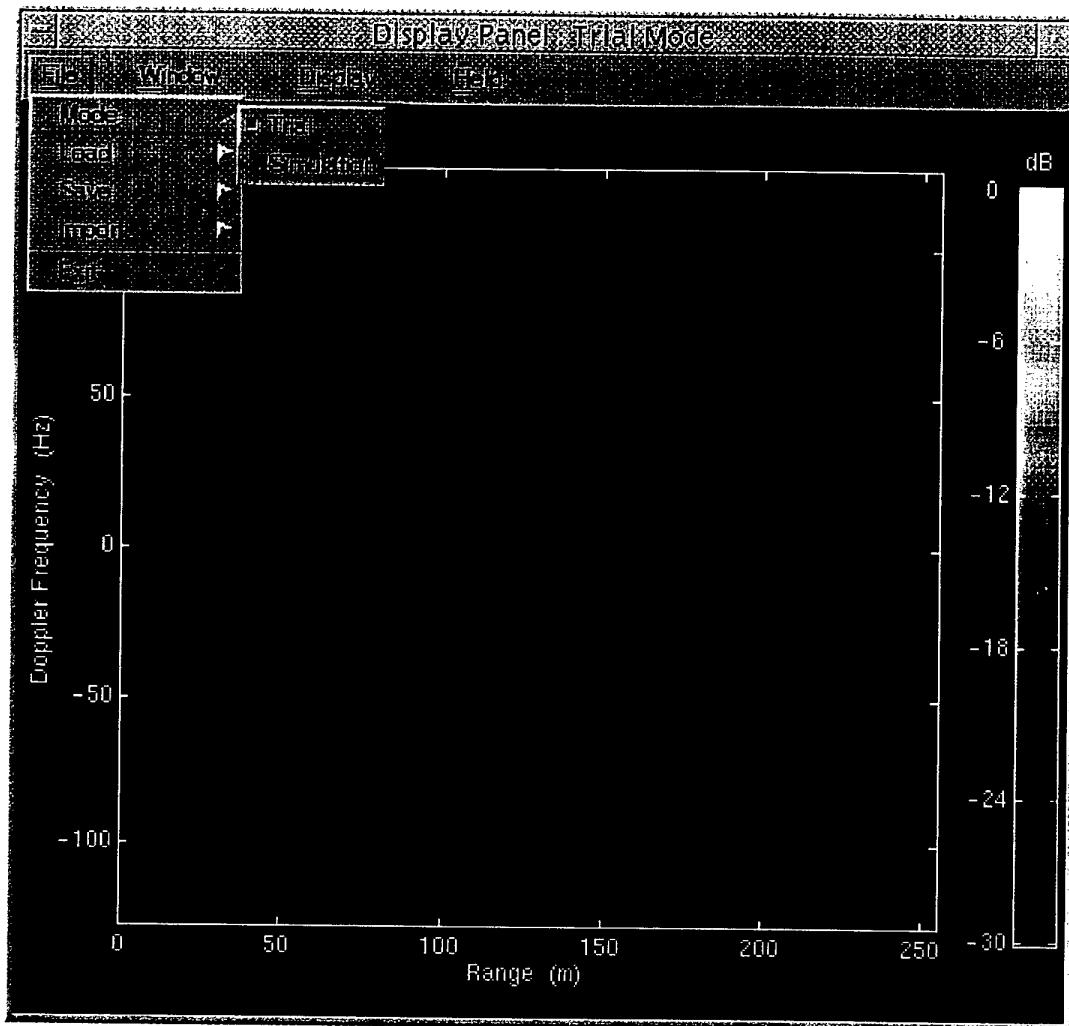


Figure 8: The Display Panel showing the File pull-down menu.

9.1.2.2 Load menu

This menu allows user parameters, selections and data to be loaded as required.

9.1.2.3 Save menu

This menu allows user parameters, selections and data to be saved as required.

9.1.2.4 Import menu

This menu allows raw radar data that has been previously saved in a variety of formats to be loaded from file. The Import menu only becomes active in trial mode, since in simulation mode the radar data is generated by ISARLAB.

9.1.2.5 Exit

Exiting ISARLAB is achieved by selecting this item on the **File** menu.

9.1.3 Window Menu

The **Window** menu provides access to all the user-defined information needed by ISARLAB to function. Access in this context means a way of creating new or changing existing parameter values. Figure 9 shows the items contained in the **Window** menu for simulation mode. In trial mode the **Scenario Setup** and **Induced Motion Plot** are not valid and therefore are not selectable.

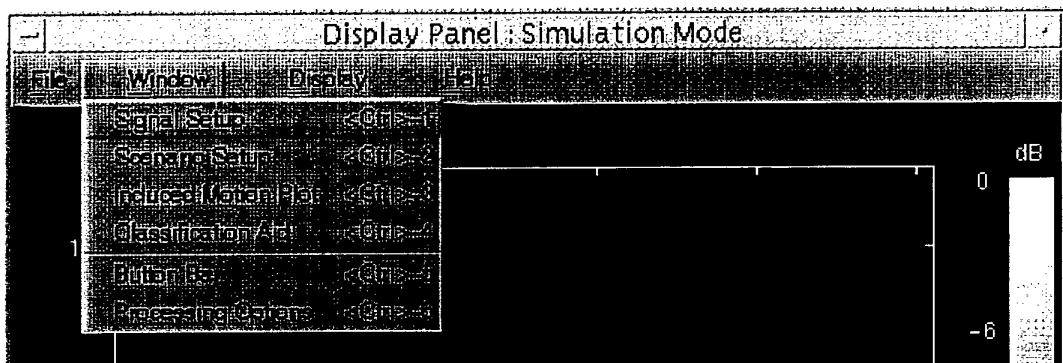


Figure 9: The Display Panel showing the Window pull-down menu.

9.1.3.1 Signal Setup

The radar's signal is characterised by a set of parameters that can be specified using this window.

9.1.3.2 Scenario Setup

For simulations, the **Scenario Setup** window is used to describe the target and radar motions.

9.1.3.3 Induced Motion Plot

A plot of the induced motion (roll, pitch and yaw) used for simulations can be displayed by selecting this item.

9.1.3.4 Classification Aid

Once an ISAR image has been generated by processing either simulated or real data, the **Classification Aid** window can be invoked. This tool allows image features to be extracted and compared with a database in an attempt to classify the target. The classification aid is described in Section 13.

9.1.3.5 Button Bar

Selecting this item simply brings up the **Button Bar** shown in Figure 11 and described in full in Section 9.1.4.3.

9.1.3.6 Processing Options

This window allows a choice of signal processing algorithms to be specified.

9.1.4 Display Menu

Choices on how to display the processed data are set using this menu. Figure 10 shows the items in the **Display** menu and with the 4-image display type selected.

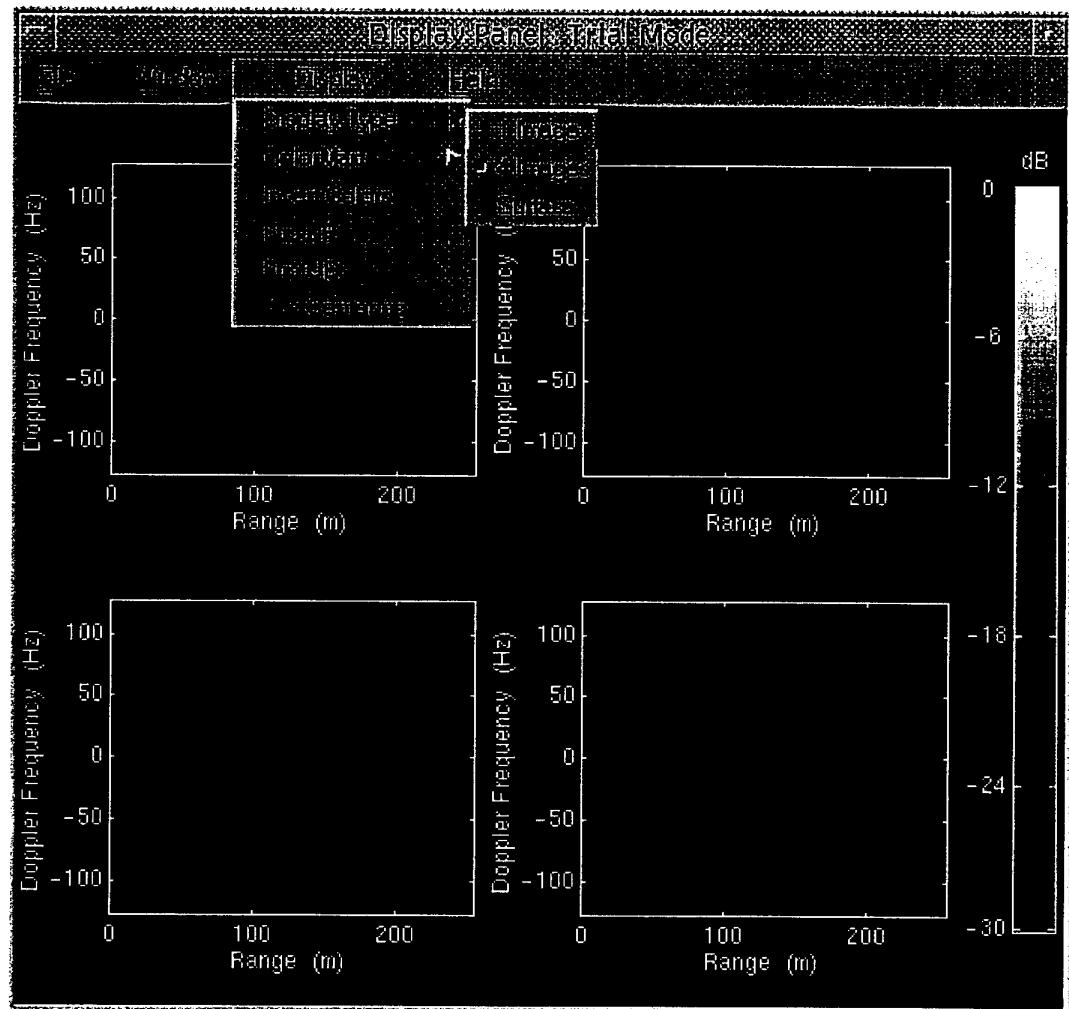


Figure 10: The Display Panel showing the Display pull-down menu.

9.1.4.1 Display Type

There are three choices of display type. The default display is a single image that is updated with every frame displayed. A 4-image display can be selected so that the frames are updated in a clockwise order starting from the upper left image. At any stage while displaying images in this mode, frames can be frozen by simply clicking the mouse button when the cursor is within that quadrant. When one or more frames are frozen, new images continue to be displayed cyclically in the remaining quadrants. Selecting a frozen quadrant releases it for use. The third choice is a single image, but in this case displayed as a surface plot that uses pixel interpolation to give a smooth texture. More information about MATLAB's Image and Surface objects can be found in the reference guide *Using MATLAB* [18].

9.1.4.2 ColorMap and Invert Colors

A selection of colour maps is available for displaying images and range profiles. The colour maps available in ISARLAB consist of most of the standard ones available within MATLAB (without prism and flag), plus two others designed specifically for displaying radar imagery (green and gsar). A short description of each colour map is provided in Table 2. Any colour map is also available in inverted form (highest and lowest hues are reversed) by selecting the Invert Colors toggle button.

Table 2: Available colour maps.

hsv	hue-saturation-value
gray	linear gray-scale
hot	black-red-yellow-white
cool	shades of cyan and magenta
bone	gray-scale with a tinge of blue
copper	linear copper-tone
pink	pastel shades of pink
green	a green version of hot: black-green-yellow-white
jet	a variant of hsv
gsar	MIT Lincoln Lab SAR imagery: black-green-yellow-white

9.1.4.3 Flip LR and Flip UD

These toggle buttons cause the image to be flipped left-to-right (LR) or up-to-down (UD).

9.1.4.4 Xcc Centering

Cross-correlation of the current image with a reference image gives an estimate of the shift between the two and therefore can be used to centre image frames. Pressing this toggle button makes the current image into the reference image and turns this form of centering on. A small window pops up to allow manual adjustments of the reference

image's position within the display area. This facility is mainly used when wanting to produce ISAR movies that exhibit smooth transitions from frame to frame.

9.1.5 Features Menu

This menu relates to the manual extraction of features for the **Classification Aid** and only appears when that window is invoked. This menu is described in Section 13.

9.1.6 Overlay Menu

This menu relates to the manipulation of 2-D schematic target overlays for the **Classification Aid** and only appears when that window is invoked. This menu is described in Section 13.

9.1.7 Help Menu

Information about ISARLAB and on-line help is obtained using the Help menu.

9.2 The Button Bar

9.2.1 Purpose

The images that ISARLAB produces can be presented continuously or in a "freeze frame" manner and the sequence of images can be recorded then replayed. These functions are performed using the **Button Bar**, shown in Figure 11, which has been designed with the familiar tape-recorder metaphor and is summarised in Table 3.

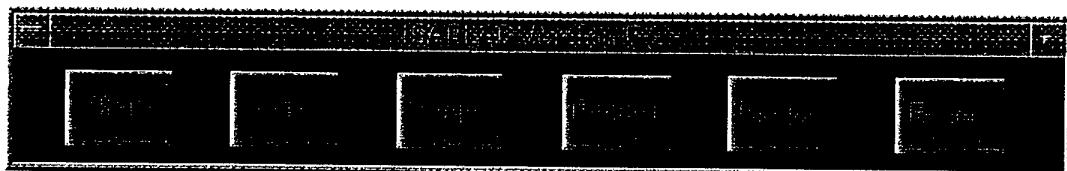


Figure 11: The Button Bar.

Table 3: Tape recorder button functions.

Button	Function	Used after hitting
STOP	Stop play or replay	Any button
PLAY	Continuous processing and displaying	STOP, STEP, PLAY
STEP	Single iteration processing and displaying	STOP, STEP
RECORD	Toggle recording mode	STOP, STEP, PLAY, REPLAY
REPLAY	Replay currently loaded movie	STOP, REPLAY
RESET	Several functions (see below)	STOP

9.2.2 Using this window

To display images continuously, hit the **Play** button. After a short while, the button should light up in green, unless a message is displayed informing you that data needs to be read in (trials mode) or the scatterer model needs to be read in (simulation mode) or that a signal has not be defined (both modes).

To stop the images from being presented, hit the **Stop** button. The **Play** button will return to its original color after the next image is processed and displayed.

To process only one image, display it and then to return to the stopped state, hit the **Step** button. This button will go green (or display the same messages mentioned for the **Play** button), display an image, then return to its original color. ISARLAB will then wait for your next action. **Step** is equivalent to **Play** followed immediately by **Stop**.

Replay plays a stored sequence of images. This is commonly referred to as a "movie". When **Replay** is pressed one of two things can happen. The first is that a message is displayed informing you that no movie has been recorded. In this case either create a movie by hitting the **Record** button (if it is not on) and hit **Step** or **Play** to begin recording, or alternatively, load a movie from the **File** menu (discussed in Section 10.1). If such a message was not displayed the button will go yellow and a new window called **Movie Options** will appear. This window, shown in Figure 12, allows the user to specify, with the aid of slide bars, the frame rate and number of loops of the movie to play. Once done, hitting the **Play** button will bring up the **Movie Panel**, which resembles the **Display Panel**, and the movie sequence will be run. The other buttons on the **Movie Options** window allow the sequence to be stopped before it has completed and closed down.

If the **Record** button has been turned on (by pressing it and it turning red) while producing images with **Step** or **Play**, the next image produced will be appended as a frame on the currently stored movie. When all the desired frames have been collected, the movie can be replayed and if required, stored using the **File** menu mentioned earlier. The **Record** button can be pressed again during continuous play in which

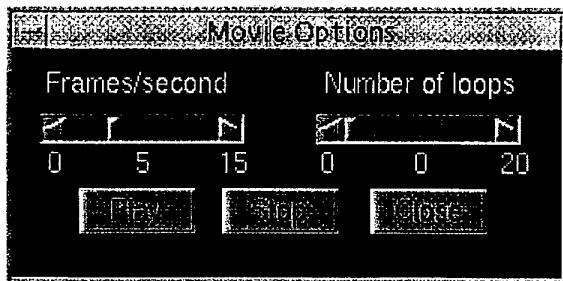


Figure 12: The **Movie Options** window.

case recording will be turned off after the next image is produced.

The **Reset** button has been added to the **Button Bar** as a convenience and performs several functions as follows (turning white while performing these functions before returning to its original color):

- it turns recording off (which is seen by the **Record** button going from red to its original color);
- resets the image counter, which is used to generate each image's title on the **Display Panel**;
- blanks the **Display Panel**;
- clears the current array of filedata, if selected on the **Reset Options** window;
- clears the current movie, if selected on the **Reset Options** window; and
- finally, in simulation mode only, it also sets the scenario and scatterer positions and induced motion state to those that existed at the start of the simulation.

10. Using Trial Data

10.1 Data Input Using the Load Menu

10.1.1 Purpose

The Load pull-down menu (Figure 13) allows trial data, radar signal parameters, an animated "movie" of images or user preferences to be loaded. A similar Save menu allows the same things to be save to file. These facilities are designed to stop the user wasting time repetitively entering parameters and also avoid the need to remember them.

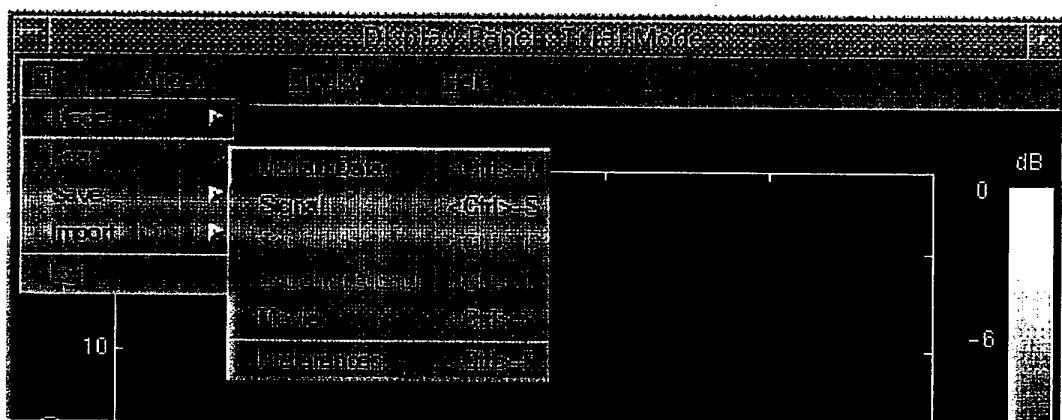


Figure 13: The Display Panel showing the File Load pull-down menu.

10.1.2 Using this window

1. Change to a working directory (if the current directory is not the one that holds the desired information). This step is unnecessary if you prefer to use full paths or browse through directories when inputting the filenames in step 3.
2. Select the Load (or Save) menu then the item you wish to load (or save), for example a file of Matlab Data.
3. A standard file selection dialogue window (Figure 14) will popup and the filename can be typed in the appropriate place or selected from the list. Entering filenames is explained in Section 8.2.4.
4. Once the filename has been found or entered, press the **Done** button and the file will be loaded (or saved).

Shortcut keystrokes are available for all of the load and save functions, as well as some other functions. These operate by simply typing the key combination (e.g. **<Ctrl>-M** for loading Matlab Data) while the cursor is anywhere within the **Display Panel**.

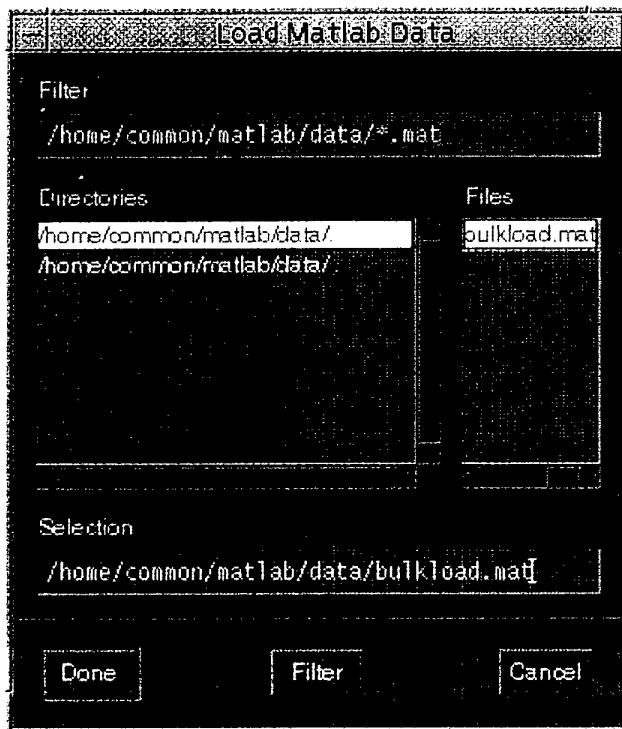


Figure 14: The Load Matlab Data window used for file selection.

10.2 Data Input Using the Import Menu

10.2.1 Purpose

Radar returns, collected on experimental trials and referred to as raw data, are read in with the Import window (Figure 15). The raw data can be thought of as a number of lines made of the same number of samples per line. The data can be in a variety of binary formats, but always as I/Q pairs. A sub-block of samples can be read by specifying the starting sample, number of samples to read starting from this sample, the starting line and the number of lines to read starting from this line (Section 4.2). In this way, after experimenting a little with the data, only data of interest can be read and processed. Some raw data formats incorporate file or record headers that contain auxiliary information about how the data was collected. Signal parameters can be automatically set up using this auxiliary information, if available in the particular data format being used.

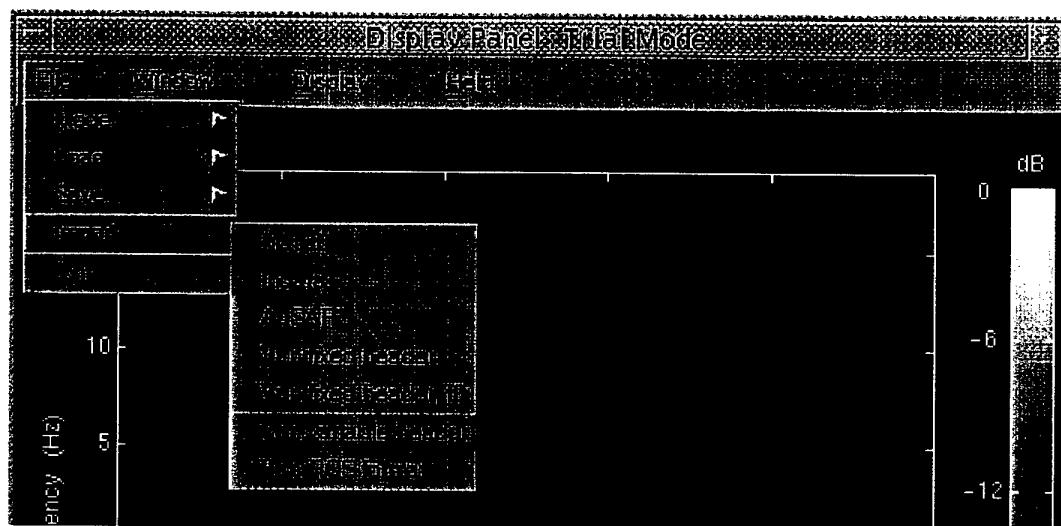


Figure 15: The Display Panel showing the File Import pull-down menu.

10.2.2 Using this window

1. Select the data format from the pull-down menu appropriate to the data file about to be read. If this is not known, consult the source from which the data was received. Meaningless data may result from using an incorrect data format.
2. A standard file selection dialogue window (left side of Figure 16) will popup and the filename can be typed in the appropriate place or selected from the list. Entering filenames is explained in Section 8.2.4.
3. The **Data Import** window (right side of Figure 16) will then appear.

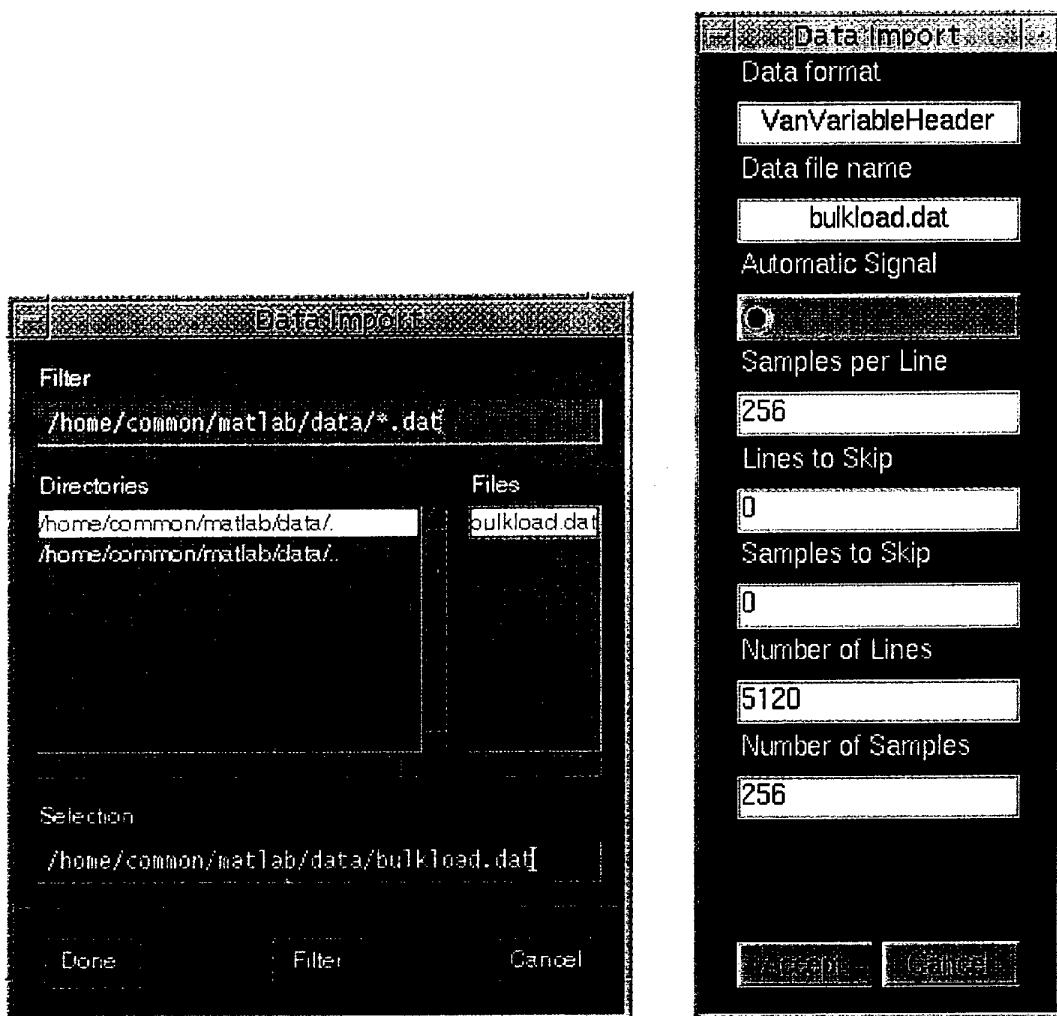


Figure 16: The Data Import file selection dialogue window and the Data Import window.

4. If you want ISARLAB to try to generate the signal parameters automatically, turn the Automatic Signal radio button ON. If no signal can be generated, an informative message will be generated.
5. As the file is a continuous sequence of samples with no delimiters between lines, ISARLAB needs to know how many samples there are in a line of samples. This information is entered in Samples per Line.
6. The starting line is entered with Lines to skip. A value of 0 means start at the first line.
7. The starting sample is entered with Samples to skip. A value of 0 means start at the first sample.

8. The total number of lines to be read is entered in **Number of Lines**.
9. The number of samples per line to be read (starting from the starting sample) is entered in **Number of Samples**.

The result of these steps is that the I and Q pairs are converted to a complex matrix of dimensions 'Number of Lines' by 'Number of Samples'. This data can be saved in MATLAB format and loaded later to avoid repeating these steps and to replace the reading and conversion process with a more efficient loading of data.

11. Simulation

11.1 Data Input Using the Load Menu

This menu allows the radar signal, the target scatterer model, the scenario, or user preferences to be loaded. This menu has exactly the same purpose and works in exactly the same way as it did in Trial mode (described in Section 10.1). The only differences between the two is the addition of the Scatterer Model and Scenario information, which are applicable only for simulations, and the disabling of Matlab Data loading, which has no meaning for simulations. The saving of data and information, however, is exactly the same in both Trial and Simulation modes.

11.2 Specifying Dynamics: Scenario Setup

11.2.1 Purpose

The radar's or target's gross motion is specified using the **Scenario Setup** window (Figure 17). A full description of how motion is modelled can be found in Section 3.1. The following is a summary.

The radar or target motion can be described as either stationary, moving in a straight line or in a horizontal circle. These are approximations to real manoeuvres (at least in short periods of time). Motion is defined relative to a 3-D right-handed coordinate system.

For linear motion the **X Position**, **Y Position** and **Altitude** specify the position in space and the **Velocity** and **Acceleration** are scalars that are in the direction of **Heading** and parallel to the x-y plane. **Heading** is measured in degrees where the zero reference is the x-axis and increases in a clockwise sense (looking into the z-axis towards the origin). **Climb rate** is defined to be vertical velocity (parallel to the z-axis and positive for the same direction).

With circular motion, the radar or target is on the circumference of a horizontal circle (parallel to the x-y plane). Hence the (X,Y) position of the radar or target and the (X,Y) position of the centre of the circle define its radius and the altitude of the radar or

target is also the altitude of the circle. The rate of rotation is proportional to the (instantaneous) speed that is set by the user. A positive speed means the circle is traversed in an anticlockwise sense (looking into the z-axis towards the origin). Speed and rotation rate are related by

$$\text{Rotation Rate} = \frac{\text{Instantaneous Tangential Speed}}{\text{Radius}}$$

Induced motion only applies to the target and refers to the roll, pitch and yaw induced on the target due to forces by the sea on ships and to a lesser extent by the air on aircraft.

11.2.2 Using this window

To describe the radar or target dynamics:

1. Select **Scenario Setup** from the **Window** menu on the **Display Panel** window. Wait for the **Scenario Setup** window to appear (left side of Figure 17).

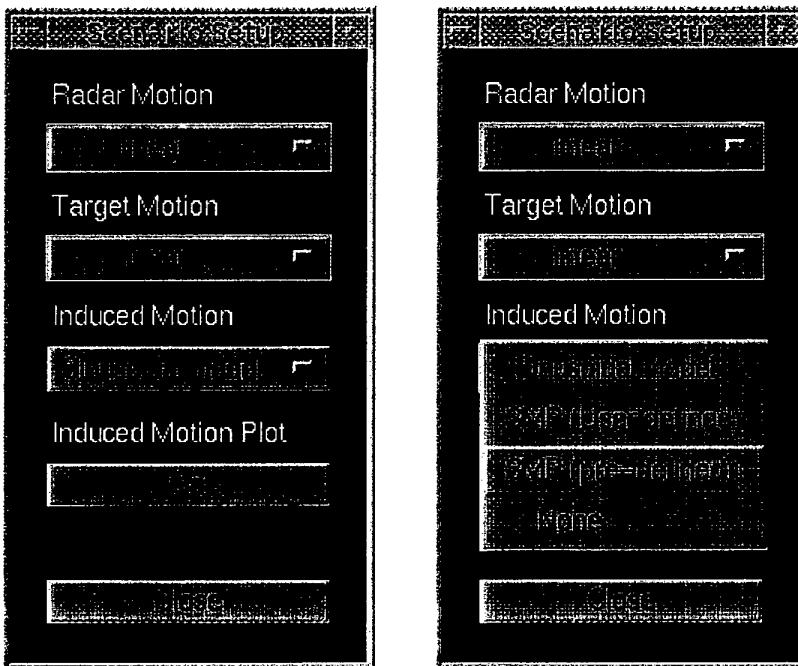


Figure 17: The Scenario Setup window and the same showing the Induced Motion menu.

2. To specify the radar as stationary, in linear motion or circular motion select the corresponding option from the **Radar Motion** popup menu. A new window

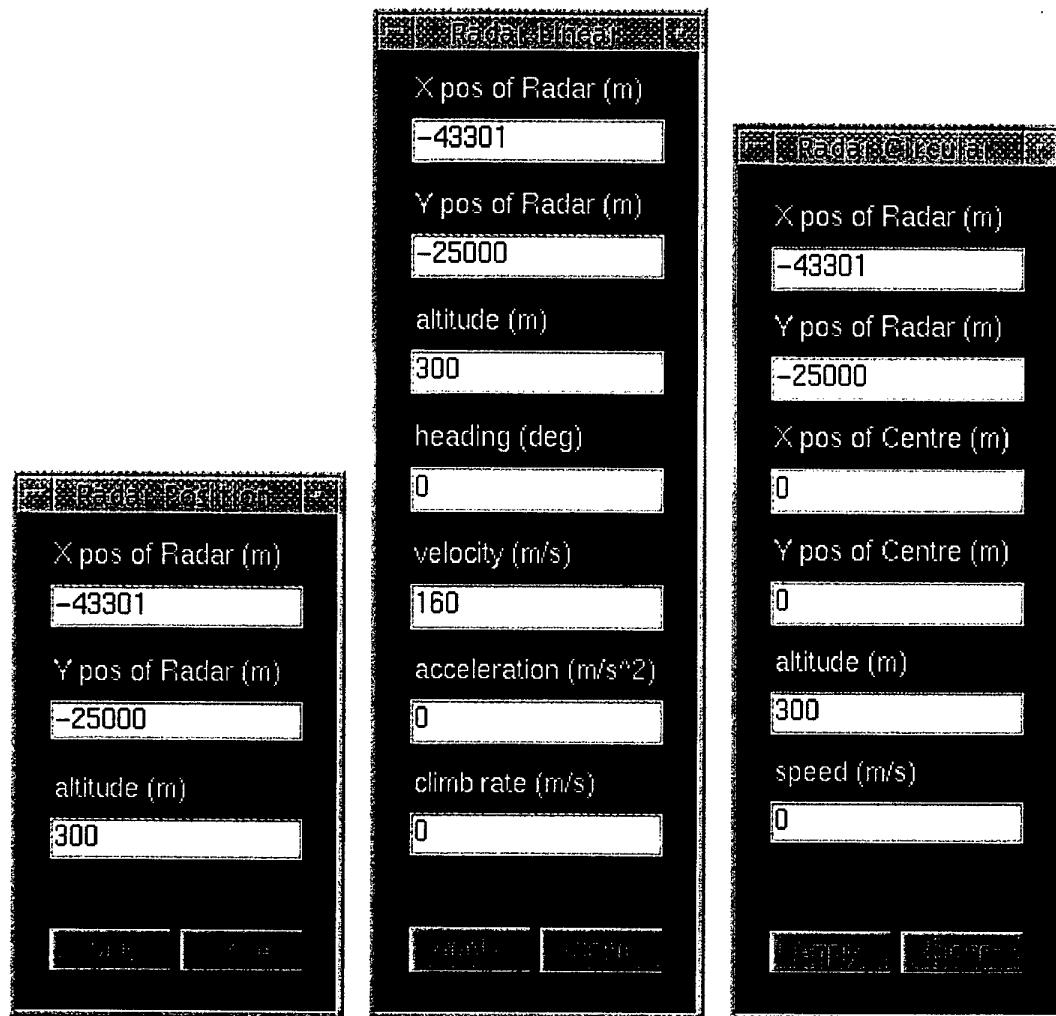


Figure 18: The Position, Linear Motion and Circular Motion windows.

will appear that will allow you to enter the specifics of the motion as described above. The three window types are shown in Figure 18.

3. To specify the target as stationary, in linear motion or circular motion select the corresponding option from the Target Motion popup menu. A new window will appear that will allow you to enter the specifics of the motion as described above. These windows are functionally identical to those shown in Figure 18.
4. To specify the induced motion for the target, select one of Sinusoidal model, SMP (User defined), SMP (pre-defined), or None from the Induced Motion popup menu. If the sinusoidal model option is chosen, the Induced Motion window that appears (left side of Figure 19) will allow you

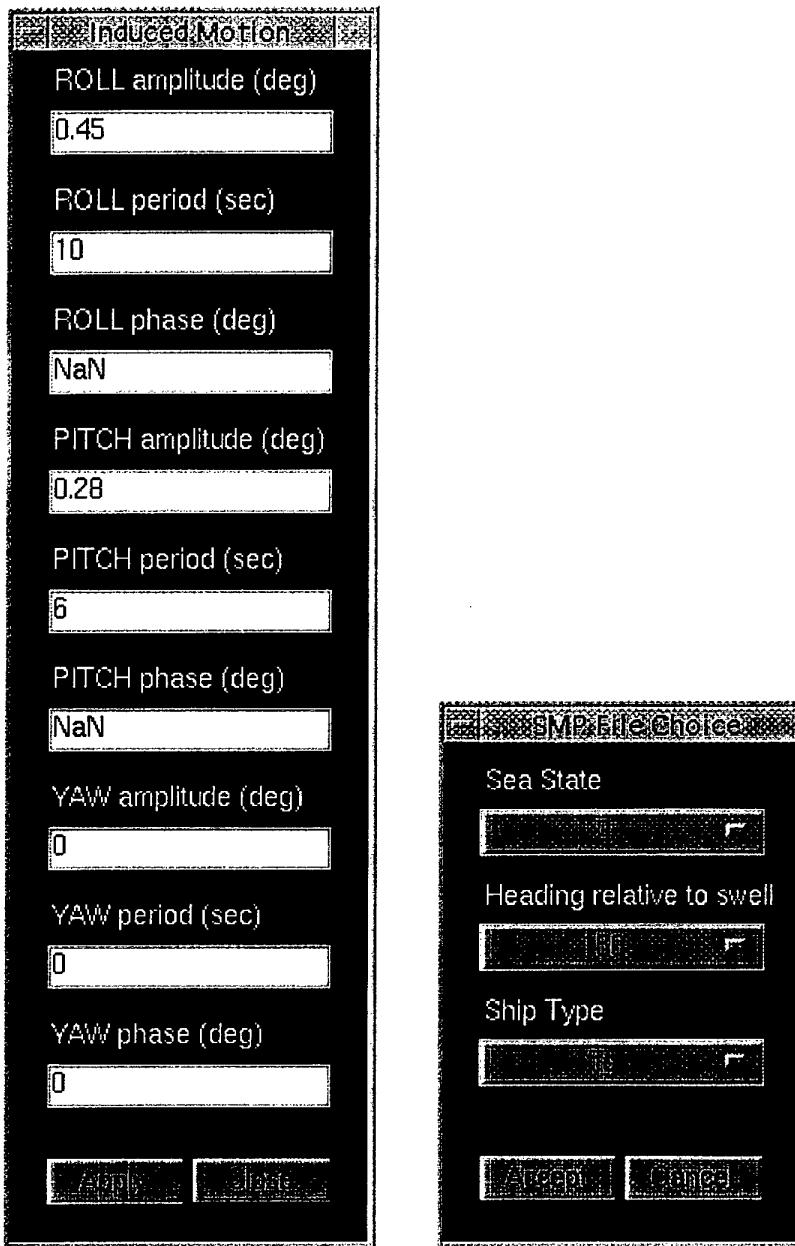


Figure 19: The Sinusoidal model Induced Motion window and the SMP File Choice window.

to enter the amplitudes, periods and a phase offset for the roll, pitch or yaw of the target. Note that:

- A zero amplitude roll, pitch or yaw means that there is no corresponding roll, pitch or yaw.
- A zero period is illegal when the amplitude is non-zero.

- If the phase is left blank (this is different from a zero (0) value for phase) then a random phase is used. This random value can be seen by hitting the **Apply** button then reinvoking the Induced Motion window.

If the **SMP²** (pre-defined) option is chosen, the **SMP File Choice** window that appears (right side of Figure 19) will allow a file of roll, pitch and yaw motion data to be selected from a database. This database is indexed using Sea State, Heading relative to swell and Ship Type, but only for restricted instances of these parameters. The **SMP** (User defined) option allows a similar file to be selected, but in this case the file could be generated by **SMP** using arbitrary parameters. This option also allows measured ship motion data to be used, providing the same MATLAB array format is used.

5. Pressing the Induced Motion Plot **Go** button will bring up the **Target induced motion graphic** window, an example of which is shown in Figure 20. This window contains plots of the induced motion used in the simulation and shows with a red marker the segment of roll, pitch and yaw motions encompassed by the current image frame. The Time field in the bottom right corner of the window can be edited to change the time extent displayed in the plots.

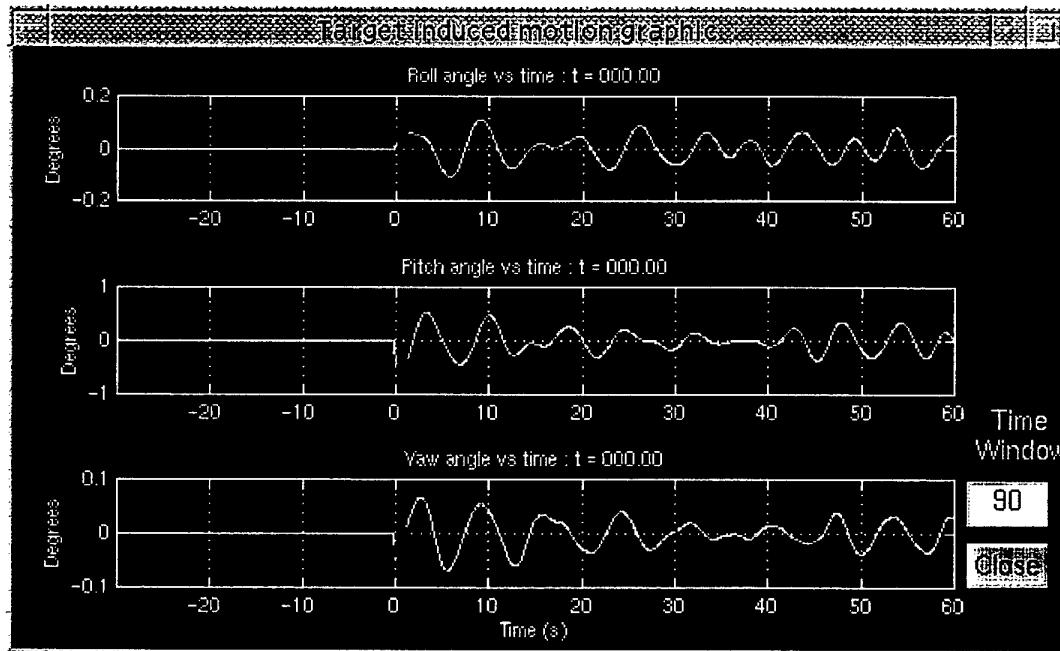


Figure 20: The Target induced motion graphic.

² SMP is a Ship Motion Program that is run off-line to produce files of roll, pitch and yaw angles as a function of time for various parameters [4].

6. To have the changes acknowledged click the **Apply** button. This updates the induced motion parameters and keeps the window visible. Then click **Close** to quit the window.
7. To disregard the changes click the **Close** button. The parameters will not change and the window will disappear.

12. Signal Processing

12.1 Choosing the Radar: Signal Setup

12.1.1 Purpose

This window (Figure 21) is used to define or modify the radar signal waveform characteristics to be used. The two most common high bandwidth waveforms used in high-resolution radars are stepped frequency and linear frequency modulation (chirp). ISARLAB accommodates both of these waveforms as well as being able to accept already compressed linear frequency modulated data. The **Waveform Type** indicates how these parameters are interpreted. The parameters required for each waveform are listed below:

- Waveform type (Stepped Frequency, Compressed LFM or Uncompressed LFM)
- Centre frequency (GHz)
- Frequency bandwidth (MHz)
- Pulse width or duration (μ s)
- Pulse or burst repetition frequency (Hz)
- Sampling frequency (kHz)
- Number of samples per pulse/burst
- Number of pulses/bursts per image
- Signal to noise ratio (dB)

Note that in the case of the stepped frequency waveform, the bandwidth is referred to as effective because it is synthesised from a number of discrete frequencies. The term burst refers to the transmission of a series of discrete frequency pulses. The sampling frequency is therefore the rate at which pulses in this burst are transmitted. For more information, see Section 3.3.

12.1.2 Using this window

To see or modify the parameters:

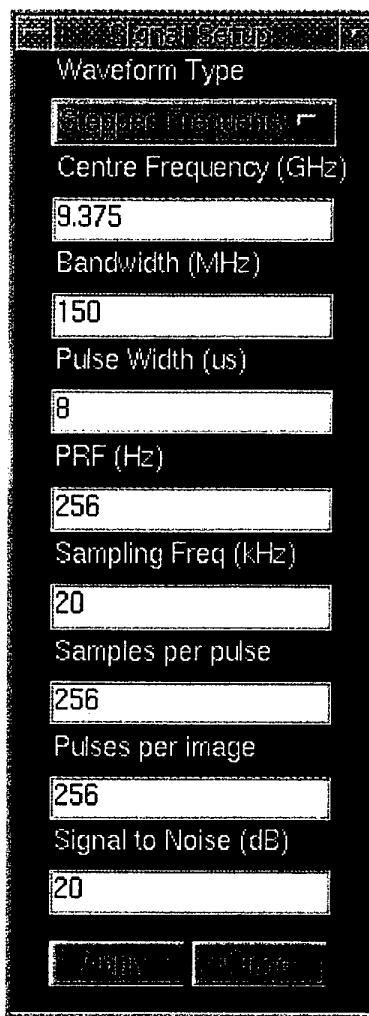


Figure 21: The Signal Setup window.

1. Select **Signal Setup** from the **Window** menu on the **Display Panel** window. Wait for the **Signal Setup** window to appear.
2. To view the parameters and not make any changes, click the **Close** button when finished viewing. This will quit the window without any effect.
3. Alternatively modify any number of parameters you like.
4. To disregard the changes click the **Close** button. The signal will not change and the window will disappear.
5. To have the changes acknowledged click the **Apply** button. This updates the signal and keeps the window visible. Then click **Close** to quit the window.

12.2 Changing How it's Done: Processing Options

12.2.1 Purpose

Processing options (Figure 22) allow changes to the signal processing used to produce the display output. This includes a choice of using Fourier processing to produce an ISAR Image, a single Range Profile or a series of Range Profiles. Range and Doppler centering and the number of range and Doppler cells to process and display, are selectable. Also, a choice of motion compensation algorithms and signal processing windows is also available. Producing an ISAR image with no motion compensation, no windowing, use of all available range and Doppler cells and no range or Doppler centering is the default.

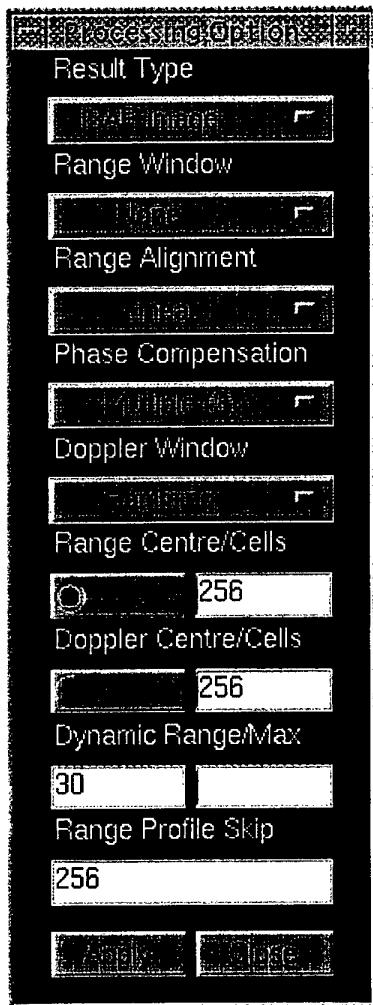


Figure 22: The Processing Options window.

The signal processing can result in one of the following Result Types or outputs:

- an ISAR image (produced using Fourier processing)
- a series of Range Profiles
- a single Range Profile (coherently averaged)
- a single Range Profile (non-coherently averaged)

If windowing is needed, it is available in both range and Doppler directions by using the Range Window or Doppler Window popup menus. The windows available are:

- Bartlett
- Blackman
- Hamming
- Hann
- Triangular

Motion compensation involves choosing Range Alignment and/or Phase Compensation. There are currently three choices of range alignment Linear, Quadratic and Cubic, which refer to the order of curve fitting applied to the estimate of range misalignment. Phase compensation, if selected, can be done using the Dominant scatterer or Multiple scatterer (using 2, 3 or 4 scatterers) algorithms, or PGA (Phase Gradient Algorithm).

Range centering calculates the location in range of the target's centre of mass and rotates the range bins to put that location in the center of the range axis. Range centering is also used to keep the target roughly in the same position on the screen for making movies. Doppler centering is performed in exactly the same way as range centering. However, it is rarely used when phase compensation is employed because that process automatically centres the target on zero Doppler frequency.

The number of range cells to use may be reduced from the maximum available to speed up processing or to look at a subset of the image. The number of Doppler cells displayed may also be reduced from the maximum available, but this in no way affects the processing.

If the Dynamic Range is specified using only a range in decibels (and the maximum left blank), autoscaling occurs. Autoscaling sets the maximum value in the image or range profile(s) to 0dB and lower values to negative decibels. If the maximum is set, autoscaling does not occur and the image is clipped both above the maximum and below the dynamic range.

In Trial mode it is possible to form image frames from contiguous blocks of data or from overlapped blocks. The Range Profile Skip field allows the user to specify

this overlap. The default skip is the same size (in number of profiles) as an image frame (i.e. no overlap). This facility is useful when producing animated movies with smooth transition from frame to frame.

12.2.2 Using this window

To see or modify the options:

1. Select Processing Options from the **Window** menu on the **Display Panel** window. Wait for the **Processing Options** window to appear.
2. To view the current options and not make any changes, click the **Close** button when finished viewing. This will quit the window without any effect.
3. Alternatively modify any number of parameters you like. Changes to some parameters and the radio buttons are immediate and are reflected in changes to the **Display Panel** axes.
4. To disregard the changes click the **Close** button. The signal will not change and the window will disappear.
5. To have the changes acknowledged click the **Apply** button. This updates the processing options and keeps the window visible. Then click **Close** to quit the window.
6. Choose the signal processing Result Type you wish from the list. If the **Display Panel** is up then you should expect that selecting a different result from the current one will clear the image, the image title and axes.
7. If the range dimension is to be windowed, select a window other than None from those available in the Range Window list.
8. Choose the Range Alignment algorithm you wish from the list.
9. Choose the Phase Compensation algorithm you wish from the list. It is recommended to use phase compensation when doing range alignment.
10. If the Doppler dimension is to be windowed, select a window other than None from those available in the Doppler Window list.
11. If Range centering is ON (default is OFF) the radio button will be "depressed". Press the Range Centre button to toggle between ON and OFF.
12. The default number of Range Cells is the maximum number available, as defined in the **Signal Setup** window. If this number is less than the maximum then this smaller number of range cells is used evenly about the range centre of the display. This has the effect of magnifying the target in the display so that if it has a small extent compared to the total range extent it now fills more of the display. The danger of decreasing the number of range cells

too much is that the target may not be wholly visible within the **Display Panel** window. Decreasing the number of range cells displayed also has the effect of decreasing processing time.

13. If Doppler centering is ON (default is OFF) the radio button will be "depressed". Press the Doppler Centre button to toggle between ON and OFF.
14. The default number of Doppler Cells is the maximum number available, as defined in the **Signal Setup** window. If this number is less than the maximum then this smaller number of Doppler cells is used evenly about the centre of the display (i.e. zero Doppler frequency). This has the effect of magnifying the target in the display so that if it has a small extent compared to the total Doppler extent it now fills more of the display. The danger of decreasing the number of Doppler cells too much is that the target may not be wholly visible within the **Display Panel** window.
15. To enter the dynamic range:
 - For autoscaling, clear (if it is not already) the Max field. If autoscaling is not required, enter a maximum dB value.
 - Enter a number in dB in the Range field.
16. Enter the value for Range Profile Skip to be any reasonable integer between zero and the total number of profiles in the data set minus the image frame size. Negative numbers are allowed and have the effect of moving backwards through the data when stepping or playing.

13. Classifying Ship Targets

13.1 The Classification Aid

13.1.1 Purpose

The classification aid is the only portion of ISARLAB that has been designed with ship imaging and ship classification in mind. That is not to say that the tool could not be applied to other types of target, but it has been optimised for extracting features along a ship's length. This restriction is reflected in the structure of the database that contains feature vectors of known target classes.

13.1.2 Using this window

To classify a target after generating a real or simulated image:

1. Select Classification Aid from the Window menu on the **Display Panel** window. Wait for the **Classification Aid** window to appear (Figure 23).

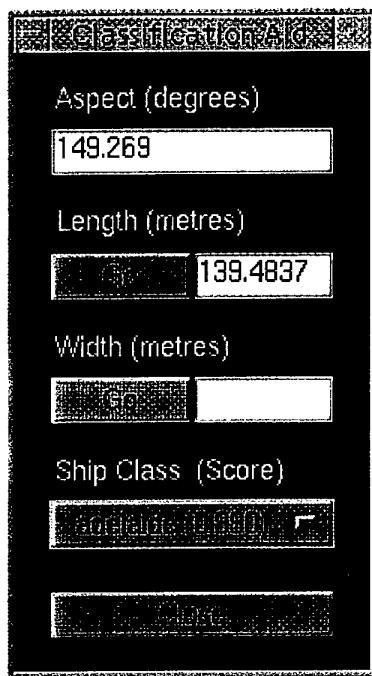


Figure 23: The Classification Aid window.

2. Enter the aspect angle (in degrees) between the radar and target. In Trial mode this should be obtained from auxiliary information recorded with the data. Otherwise in Simulation mode a value corresponding to the simulated scenario will be automatically entered in the Aspect edit-box. An aspect angle is mandatory for all of the following operations to function. If unknown, a value of zero (0) can be entered and the length and width calculations will then give minimal values.
3. To obtain the length of the target, click the Length button. ISARLAB will prompt you to click on the bow and stern of the target (in that order). The aspect angle corrected distance between those two points will be displayed in the Length text-box. ISARLAB will then automatically compare this "unknown" target length with that for all the known targets in the database and return a list of names in the Ship Class popup-menu in decreasing order of matching score. Successful operation will obviously depend on an image in which the bow and stern are discernable.
4. Target width is extracted in a similar manner by clicking the Width button. ISARLAB will prompt you to click on both sides of the target. This should be done at the position where the target image appears widest and the two points need to be at the equivalent place on either side. When a value is displayed in the Width text-box, the classification algorithm is re-run to give a new estimate of target class that then updates the list of names in the Ship Class popup-menu.

5. Once an initial classification has been done, the **Features** menu on the **Display Panel** window will appear. Following visual identification of one or more structural features along the ship's length, this pull-down list allows a feature type to be chosen, an importance rating to be assigned to it and then its position relative to the ship's bow to be extracted with a mouse click. After each feature has been identified/extracted, the classification algorithm is re-run to give a new estimate of ship class.
6. To activate the overlay facility, select a name from the **Ship Class** popup-menu and a 2-D schematic drawing of the ship will be superimposed on top of the image. Each overlay has been correctly scaled to represent the target's true length in range at the specified aspect angle. Manipulation of the target overlay to achieve a better visual match with the image is done using the **Overlay** pull-down menu on the **Display Panel** window. Three overlay manipulation functions are currently implemented:
 - **Stretch** is used to make the overlay fit the image and is achieved by clicking and dragging a bounding box into which the schematic drawing is stretched.
 - **Translate** allows the overlay to be moved to any position within the display and is done by dragging a point on the schematic to the desired point on the display.
 - **Rotate** is simply rotation of the overlay about the x, y and z-axes of the display. This is performed by entering one or more angle values into the **Rotate Overlay** window that pops up after selecting the rotate function.
7. To restart the classification tool you can press the **Length** or **Width** **Go** buttons, or press the **Close** button then reopen the **Classification Aid** window.

14. The Display Panel

The results of all the processing and display options for the data that was either, input from a file of sampled radar returns or simulated by ISARLAB, is presented in the **Display Panel**; an example of which is shown in Figure 24. This window appears on starting up ISARLAB and comprises two parts. The legend reflects the colors that correspond to different intensity levels in the image and is on the right side of the window. The axes to the left of the legend bound where the image appears. The title over the image reflects the source of the data, the number of the first and last records of the data array used in forming the image and the corresponding position in time of the first record relative to the beginning of the run.

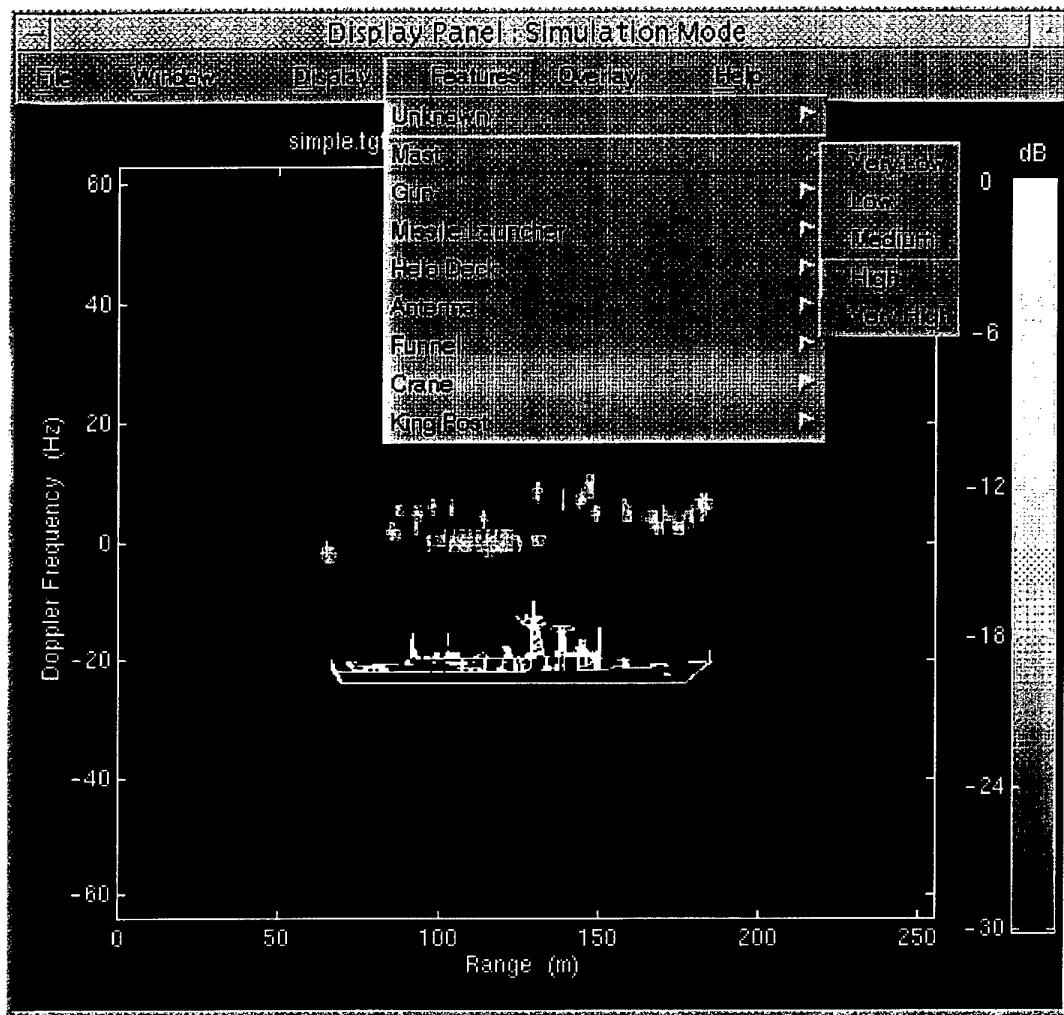


Figure 24: The Display Panel.

14.1 Miscellaneous Functions

14.1.1 Zooming

Although the zooming facility that is provided on the **Processing Options** window by selecting the number of Range and Doppler Cells appears flexible, there may be occasions when the best magnified view of the image cannot be obtained. In these situations one can resort to MATLAB's zoom function. This function can be used in a number of ways, although the easiest is to turn it on by making the **Display Panel** the active window and then simply typing `zoom` on at the MATLAB prompt. Once in this mode the image can be magnified using the mouse, by clicking the left mouse button to zoom in on the current location of the pointer or clicking the right button to zoom out. Each time a mouse button is clicked, the axes limits will be

changed by a factor of 2 (in or out). You can also click and drag a box with the left mouse button to zoom into the area defined by that box.

Care should be taken to turn zooming off (by typing `zoom off` at the MATLAB prompt) when finished, as this function disrupts the operation of the classification aid.

14.1.2 Printing

While no printing facility has been built into ISARLAB, MATLAB has an extensive range of options for printing figures. Either type `help print` at the MATLAB prompt or consult the reference guide *Using MATLAB*[18] for printing options.

15. A Quick Tutorial

ISARLAB comes with a small set of example files so that a simulation can be run immediately. To run the simulation of a simple ship sailing in a straight line in Sea State 3 while being imaged by airborne radar, do the following:

1. Change to the directory containing the example files.
2. Select **Simulation** mode from the **File** menu on the **Display Panel** window.
3. Select the **File Load** menu and the **Signal** item, then choose the file **sf_1.sig** using the Load Signal file selection dialogue window.
4. Repeat this process to load both a scenario (file: **lin150ss3.scn**) and a target scatterer model (file: **simple.tgt**).
5. The signal parameters can be seen on the **Signal Setup** window that appears after selecting the **Signal Setup** item from the **Window** menu on the **Display Panel** window.
6. To see the scenario parameters, select **Scenario Setup** from the **Window** menu on the **Display Panel** window. The **Scenario Setup** window should appear and indicate that the both the radar and the target are in linear motion and that there is no induced motion.
7. Select the current, i.e. linear, option for **Radar Motion** to see a window appear indicating that the radar is initially situated at a range of 50 km behind the target, at 300 m altitude and on a heading of 0 degrees at a velocity of 160 ms^{-1} .
8. Select the current, i.e. linear, option for **Target Motion** to see a window appear indicating that the target is initially situated at the origin, at sea level and also on a heading of 0 degrees, but at a velocity of 9 ms^{-1} .

9. Select the **SMP** (pre-defined) option from the **Induced Motion** menu and from the **SMP File Choice** window choose sea state 3, heading relative to swell of 120 degrees and an FFG ship type, then hit **Accept**.
10. To see the **Target induced motion plot** press the **Go** button on the **Scenario Setup** window
11. At this point, you can close the windows opened in each step above, leaving only those that were initially displayed, i.e. the **Processing Options** window, the **Display Panel** and **Button Bar**.
12. Hit the **Step** button on the **Button Bar**. After a moment it should go green and after a short while an image should appear. (Don't be alarmed to see that the image is unfocused).
13. To see the effect of motion compensation (focussing the image), in the **Processing Options** window select linear from the Range Alignment popup menu and Multiple (3) from the Phase Compensation popup menu and then hit **Apply**. The image will be reprocessed with motion compensation and re-displayed.
14. Next, try changing the **Result Type** on the **Processing Options** window, to each available option, followed by the **Apply** button.
15. Finally, see how changing each setting in the **Display** menu affects the image.

16. References

- [1] M.J. Muuss, P. Dykstra, K. Applin, G. Moss, E. Davisson, P. Stay and C. Kennedy, "Ballistic Research Laboratory CAD Package, Release 1.21," *BRL internal publication*, Ballistic Research Laboratory, 1987.
- [2] J.L. Gustafson, R.E. Benner, M.P. Sears, and T.D. Sullivan, "A radar simulation program for a 1024-processor hypercube," *Proceedings of Supercomputing '89*, Nov. 1989, pp. 96-105.
- [3] M.L. Harman and, S.H.W. Simpson, "EPSILON-a radar cross-section modelling," *Proceedings of the 1990 UKSC Conference on Computer Simulation*, Sep. 1990, pp. 236-43.
- [4] K.R. Shillington, P.A. Jahans, E.H. Buller, and J.K.E. Tunaley, "An ISAR simulator for ships," *Antennas and Propagation Society Symposium*, 1991 Digest, Jun. 1991, pp. 1032-5.

- [5] M.B. Murch, and M.S. McFarlin, "N-point scatterer model development of a fighter aircraft using radar cross section prediction codes," *Proceedings of the 1992 Summer Computer Simulation Conference*, Jul. 1992, pp 821-5.
- [6] D.R. Wehner, *High Resolution Radar*, Artech House, Norwood, MA, 1987.
- [7] D.L. Mensa, *High Resolution Radar Cross-Section Imaging*, Artech House, Norwood, MA, 1991.
- [8] C.C. Chen and H.C. Andrews, "Target-Motion-Induced Radar Imaging," *IEEE Trans. Aerospace and Electronic Systems*, Vol. 16, No. 1, Jan. 1980, pp. 2-14.
- [9] B.D. Steinberg, "Microwave imaging of aircraft," *Proceedings of IEEE*, Volume 76, No 12, Dec. 1988, pp. 1578-1592.
- [10] B. Haywood and R.J. Evans, "Motion compensation for ISAR imaging," Proc. Australian Symp. Signal Processing and Applications, Adelaide, Australia, Apr. 1989, pp. 113-117.
- [11] D.E. Wahl, P.H Eichel, D.C. Ghiglia and C.V. Jakowatz, Jr., "Phase Gradient Autofocus - A Robust Tool for High Resolution SAR Phase Correction," *IEEE Trans. Aerospace and Electronic Systems*, Vol. 30, No. 3, Jul. 1994, pp. 827-834.
- [12] A.V. Oppenheim and R.W. Schafer, *Digital Signal Processing*, Prentice-Hall, Englewood Cliffs, NJ, 1975.
- [13] *MATLAB Installation Guide for UNIX (Version 5.1)*, The MathWorks, Inc., Natick, MA, May 1997.
- [14] *MATLAB Installation Guide for PC and Macintosh (Version 5)*, The MathWorks, Inc., Natick, MA, December 1996.
- [15] B. Haywood, *ISAR Image Processing Toolbox User's Guide*, Microwave Radar Division, DSTO, Salisbury, Australia, October 1994.
- [16] *MATLAB Signal Processing Toolbox User's Guide (Version 4)*, The MathWorks, Inc., Natick, MA, December 1996.
- [17] *Building GUIs with MATLAB (Version 5)*, The MathWorks, Inc., Natick, MA, December 1996.
- [18] *Using MATLAB (Version 5)*, The MathWorks, Inc., Natick, MA, December 1996.

Appendix A: 3-D Linear and Circular Motion

Recall that according to Newtonian dynamics an object with a position p , velocity v and constant acceleration a will have a new position after a time t according to

$$p_{new} = p + vt + \frac{1}{2}at^2, \quad (A.1)$$

where the velocity will have a new value after the same time t according to

$$v_{new} = v + at, \quad (A.2)$$

and acceleration is a constant

$$a_{new} = a = \text{const.} \quad (A.3)$$

This motion is often referred to as "linear motion" although it is general enough to describe motion such as the parabolic trajectories that are exhibited by falling objects.

There also exists an equation to describe the new position for an object that circumscribes a circle. The circle's centre is, without loss of generality, assumed to be at the origin. The object's starting position is defined by a vector p (note that the length of p is the circle's radius) and the plane containing the circle has a unit normal α (Figure 25). If the object is rotated by an angle θ then the new position is

$$p_{new} = (1 - \cos\theta)(\alpha \bullet p)\alpha + p \cos\theta + \sin\theta(\alpha \times p) \quad (A.4)$$

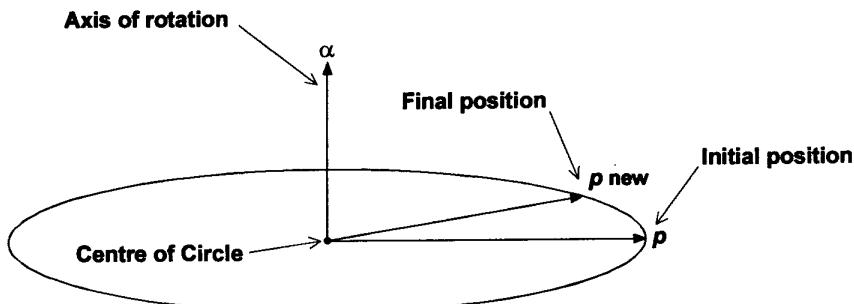


Figure 25: Definition of parameters for circular motion.

Appendix B: Raw Data File Formats

Although the majority of users of this toolbox will not need to know the exact format of the raw radar data files, the fact that a number of different formats exist means that the user should be aware of the differences. Below is a brief list of the more recent formats used by Surveillance Systems Division, the description used to select the format in the ISARLAB interface and the time period they were mostly in effect. Information in the file header, or the creation date of a given data file, should enable one to determine the file format that should be used when extracting the desired data segment.

Radar Van Formats (these are all stepped frequency waveforms):

Prior to 9/89: Not implemented in this system.

Van: fixed header, f0 format (9/89 – 1/91): These files have a 256 byte fixed length header followed by IQ pairs of received data only. The number of frequency steps per sweep is either 146 or 292. The corresponding number of sweeps is 128 or 256. The peculiar number of steps arises because the initial frequency, f0, is repeated after every seven steps. These f0 values are stripped from the data prior to processing.

Van: fixed header format (2/91 – 9/91): As above but without the f0's and with the possibility of more than 256 sweeps per record.

Van: variable header format (10/91 – date): These files have a variable length header followed by transmitted and received IQ data, with sweeps separated by a 48 byte intersweep header. The main header is terminated by a ^Z character (1A hex). The number of sweeps in a record can be very large. There can also be attenuation changes in the data at predefined intervals (typically 512 sweeps). Information on any such changes is contained in the intersweep headers.

AuSAR format: These files are 8-bit integer binary data of IQ pairs representing received, analogue range compressed and sampled linear FM (chirp) data. There is no header or other auxiliary information in the file.

INGARA format: These files are 32-bit floating point format binary data of IQ pairs representing received, sampled and digitally range compressed linear FM (chirp) data. There is no header or other auxiliary information in the file.

Appendix C: Units

The internal representation of all quantities in the system and the units used in the graphical user interface are as follows:

Table 4: Units used internally and in the graphical user interface.

Quantity	Internal Units	Units seen in the interface
Length	Metres	Metres
Time	Seconds	Seconds, Microseconds
Frequency	Hertz	Hertz, MegaHertz, GigaHertz
Angular Measure	Radians	Degrees

Appendix D: Troubleshooting

The following are some of the more common problems found when trying to form images with ISAR processing.

Problem:	Image is squashed onto zero Doppler
Possible Cause:	Insufficient relative motion between radar and target
Solution:	Modify scenario appropriately
Problem:	Image is aliased in Doppler
Possible Cause:	Under sampling
Solution:	Modify the signal to make the PRF higher
Problem:	Poorly focussed image
Possible Cause 1:	Motion compensation should be applied
Solution 1:	Modify the processing options to include motion compensation
Possible Cause 2:	Incorrect Data Format selected (Trial mode only)
Solution 2:	Read data again with the correct format from the <u>File</u> <u>Import</u> menu

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ISARLAB – Inverse Synthetic Aperture Radar Simulation and Processing Tool

Brett Haywood, Ross Kyprianou, Carmine Fantarella and James McCarthy

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19. ABSTRACT ISARLAB ("Inverse Synthetic Aperture Radar Laboratory") is a computer program designed as a research and training tool for those interested in the field of radar imaging. The system runs under MATLAB and is capable of simulating the radar returns from complex targets such as ships and aircraft, and processing these to form high range resolution (HRR) profiles and inverse synthetic aperture radar (ISAR) images. In addition to simulating various radars and targets in realistic scenarios, ISARLAB can accept and process experimentally collected radar data. This document represents the combination of a Reference Guide and a User's Guide to the software package, as well as providing a brief introduction to radar imaging.			